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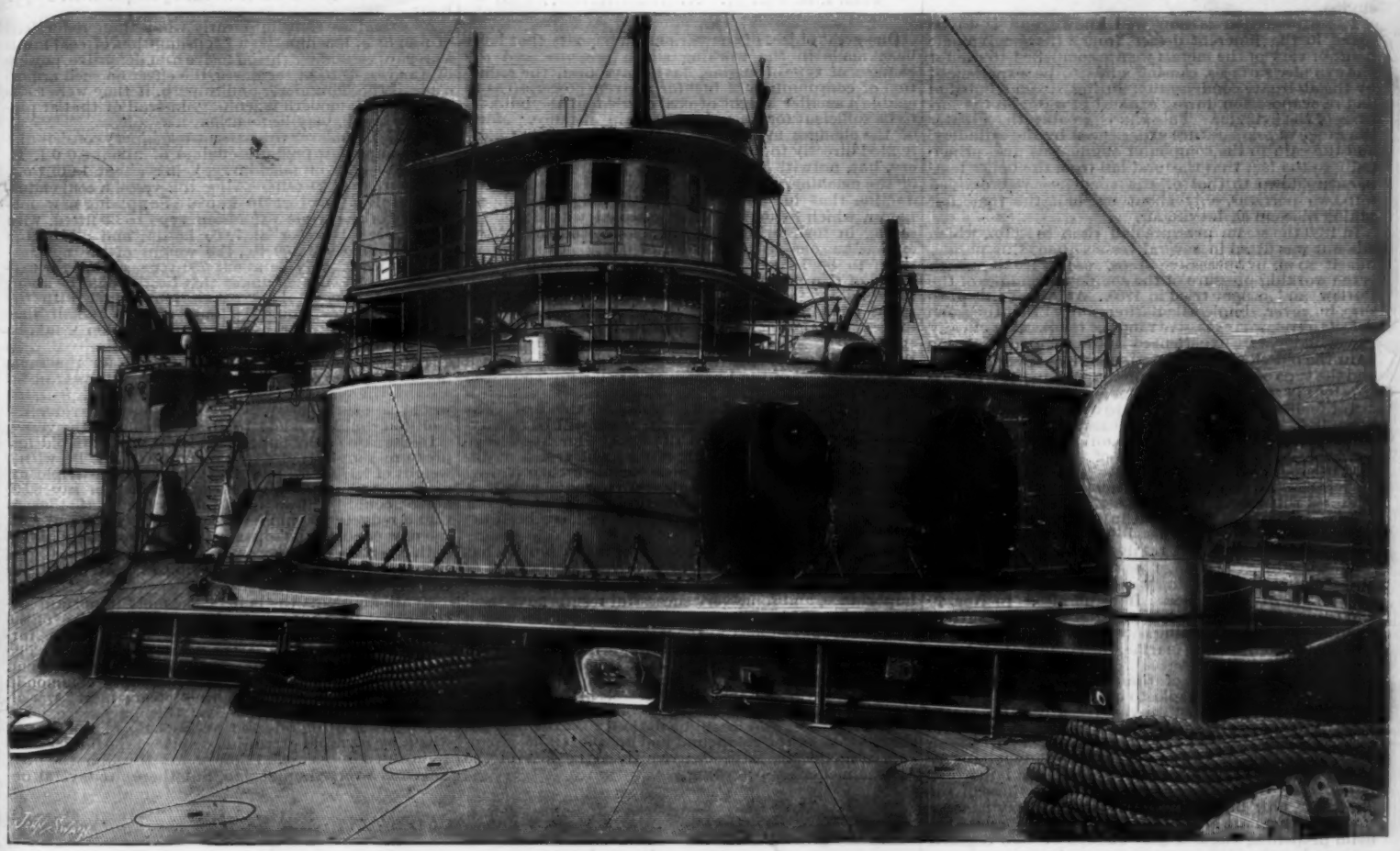
## H. M. S. VICTORIA.

In our engraving the Victoria is shown under steam, with North country coal, the engraving being enlarged from an instantaneous photograph courteously placed at our disposal by the builders of the ship, Sir W. G. Armstrong, Mitchell & Co., Newcastle-on-Tyne.

The ship was launched at Elswick on the 9th April, 1888. She is built of steel, and the principal particulars concerning her are as follows: Tonnage displacement, 10,470; indicated horse power, 14,244; length, 340 ft.; beam, 70 ft.; mean draught, 26 ft. 9 in.; speed, 17·3 knots, developed during speed trials in June, 1888; complement, 550 men. Guns, two 110 ton, 16¼ in., B. L.; one 29 ton, 10 in., B. L.; twelve 5 ton, 6 in., B. L.; twelve 6 pounder, Q. F.; nine 3 pounder, Q. F.—thirty-six. Estimated cost, £817,841. Weight of heaviest projectile, 1,800 lb.; powder charge for projectile, 960 lb.; length of biggest gun, 43 ft. 8 in. Her engines are by Messrs. Humpheys & Tennant.

The Victoria is rated as a "first-class battle ship." She is protected by a belt of 18 in. compound armor, extending about half the length of her hull; and rising 2 ft. 6 in. above the water. There is a covering deck, which extends to the bow and stern, where it is 3 in. thick.

The turret, a view of which we give above, taken from the fore deck, is plated with 17 in. armor. The two 110 ton guns will have an arc of fire from right ahead round the bow. Behind the turret is the conning tower, on the top of which is a deck house. The mast of steel is really used as a derrick post for hoisting out boats, etc. A 29 ton breech loader is carried right aft. —*The Engineer.*



TURRET OF THE BRITISH WAR SHIP VICTORIA.

## THE PROPELLING MACHINERY OF MODERN WAR VESSELS.

By H. J. Oram, Esq., Engineer R. N., of the Controller of the Navy's Department, Instructor in Marine Engineering at the Royal Naval College, Greenwich.

I think we may safely say that in no department of naval science have greater or more important changes recently taken place than in that of "marine engineering," as applied to war ships, and the object of this paper is to describe the most important of these recent changes, and some other matters of interest, in connection principally with the propelling machinery of our modern war ships. Some of these changes are simply extensions of principles which have been in application for very many years, while other important ones are of recent introduction; and a very encouraging feature of any review of the subject is the fact that those improvements which have been introduced in very recent years are very considerable ones, and as there is no more reason to think that we are approaching finality in these matters now than there was in the old days, we may anticipate still further improvements in the near future, although their direction may not be evident. Endeavors to forecast the direction in which improvements would take place have not been very successful in the past, for on looking over old papers on this subject one is struck with the frequency with which the writers confidently anticipate that improvements in efficiency would next take place in the mode of generation of the steam rather than in the method of utilizing it, whereas we know that the improvements that have occurred have been in quite the reverse direction.

It will be interesting to refer to one great change which was made many years ago in the propelling apparatus, which caused the first considerable step to be taken in the direction of increasing the speed of our vessels. This great change was the substitution of the screw propeller for the older paddle wheel, a step that not only revolutionized the internal arrangements of war vessels, and greatly increased their power of offense and defense, but also brought nearer much of the progress that has since been made in producing vessels of high speed. The screw was generally adopted in the navy about the year 1850, after the Admiralty trials between paddle and screw vessels in 1843 and 1849 had clearly demonstrated that the screw was at least as efficient as the paddle wheel as a propelling agent.

Considering all the circumstances, however, it is to be wondered at that the paddle held the place it did for so long a time, for even supposing that some little sacrifice of propelling efficiency to have been necessary, yet considering the very prominent disadvantages attending the use of the paddle, such as having the paddles themselves and important parts of their machinery above the water line, and greatly exposed to the risk of damage in action, the interference of the paddle boxes with the deck arrangements, such as those for working and training the guns, and the falling off in efficiency of the paddle on long voyages, when the draught of the vessel lightens, owing to the consumption of coal and other stores, the balance of advantage would still have been much in favor of the screw.

After the screw had been adopted, the information available at that time as to its proper proportions, all obtained from actual experiment, clearly indicated that for efficient action the ratio of its pitch to diameter should be within certain limits; and as the greatest diameter of propeller was limited by the draught of water, it occurred that the pitch required, with the speeds of engines that had up to that time been usual with the paddle wheel, was too great to be within the limits which experiment had shown to be necessary, and the only alternative was to increase the number of revolutions made by the *screw* so as to lessen its pitch. Many of the first screw vessels, however, had the same speed of *engine* as usual with the paddle wheel, the necessary increase of speed of screw being obtained by fitting gearing between the engine and propeller shaft; but the gain to be effected by omitting this cumbersome gearing, and by directly connecting the engine with the propeller shaft, being obvious, and a good deal of improvement having been effected in the workmanship of the engine, which made it possible to do this, the gearing was soon omitted, and the engine connected direct to the propeller shaft, thus working at a much higher number of revolutions than before.

These changes resulted largely in reducing the space required for and the weight of the engines; they were the first considerable steps taken in this direction, and many of the more recent developments have consisted in still further adding to the speed of the engine, with corresponding reductions in the space and weight required.

A short account of the principal steps that have accompanied the development of war-ship machinery, more especially since the introduction of the screw propeller, and up to about the year 1880, was given in a paper entitled "The Relations between the Size, Speed, and Power of Marine Engines," which was read at this Institution in 1882, by Mr. Sennett, now the engineer-in-chief of the navy. As stated there, the principal steps up to that date, since the change of type of propeller, were, *first*, the change of type of condenser from the jet condensing to the surface condensing variety, a step than which no others have been so far-reaching and important in their influence; and *second*, the alteration of type of engine, from the simple expansion type, which takes the boiler steam into a cylinder, and, after expanding in that cylinder, exhausting direct to the condenser, to the compound type, in which steam of full boiler pressure is taken into a small cylinder, and, after expanding there, is led to one or more larger cylinders in which the steam completes its expansion, and performs more work before entering the condenser. Also throughout the whole time there was a gradual increase, both in the working pressure of steam and in the speed of the engines, with a corresponding diminution of the weight of the machinery; and further, that when, on the in-

troduction of the surface condenser, the working steam pressure was raised to 60 lb. per square inch, there was an important change in form of the multitubular boiler used, from the rectangular or flat-sided type to the cylindrical type, this latter variety of boiler with certain modifications of detail still remaining the usual type at the present time.

I will now briefly describe the most important changes which have taken place in war ship machinery since the end of the period named, *i. e.*, during the last eight years, and some of the effects of those changes.

In the engine room the great improvement which has been one of the leading features of this period has been the abandonment of the ordinary compound engine, in which the expansion of the steam is carried out in two stages, and the adoption of the triple expansion engine, in which the steam expands successively in three cylinders entirely separate before finally entering the condenser. Theoretical considerations have from very early days directed the attention of engineers to the use of higher pressures of steam and more complete utilization of the property of expansion for increasing the efficiency of the engine, and hence reducing the consumption of fuel; and since the principal barrier to the use of high pressure steam was removed soon after 1860, by the adoption of the surface condenser, the rise of working steam pressure has been very considerable and particularly rapid during the last few years. The success of the compound engine compared with the simple engine is a historical fact, but it is interesting to remember now that probably no question caused more difference of opinion among engineers than as to the advisability of adopting the compound engine.

It must be admitted that theory did not assist in the suggestion of this great change, but rather the reverse, for as far as the question was then understood, there could be no difference between the amount of work to be obtained from a certain quantity of steam, whether it was expanded in one cylinder or in two or more. In fact, the explanation of the action by which the benefit was secured came *after* the success of the compound engine.

The explanation is now well known, and is to be found in the inherent defects from a thermo-dynamic point of view of the metals we are compelled to use for our cylinder surfaces, causing a loss to be experienced by the alternate condensation during steam admission and re-evaporation during exhaust of water on the surfaces of the cylinder. This loss is greater the greater the range of temperature experienced by the cylinders, and the gain in the compound engine was due principally to the fact that the total fall from the boiler temperature down to that of the condenser was divided into two portions, only about one-half the total fall taking place in each cylinder.

In 1880 the steam pressure had risen to 90 lb., which amount was fitted in several vessels about this period, but it soon, by successive steps, rose to 120 lb., which is the working pressure of the compound engines of the Curlew and others tried in 1885. At about this pressure, however, simple calculation showed that the same defects as regards excessive range of temperature in any one cylinder were experienced in the compound engine as in the old simple engine, though in a lesser degree, and the type of engine was soon changed to the triple expansion, in which, among other advantages, the total fall of temperature is split up into three separate stages. Since 1885, with a few minor exceptions, all new engines for the navy have been on this principle, the boiler pressure being in the first of them 130 lb., which has been gradually increased to the 155 lb. of the Medea class in 1887, and the same in the new vessels designed this year. The success of this type of engine has been most complete, both in the navy and in the mercantile marine, where also it has been largely adopted with very satisfactory results, the actual saving of coal effected by the change being about 20 per cent. Not only in large sea-going vessels has it been adopted, but all new torpedo boats have it also. In Nos. 79 and 80 already tried, triple expansion engines are fitted, and there are now building seven new first-class torpedo boats for our Indian marine, the engines of all being on this principle.

Although, in the case of the main engines, the first change of type from simple to compound took place as far back as 1872, it was until very recently entirely confined to the propelling engines of our vessels, the whole of the much smaller but very numerous auxiliary steam engines that occur in a large war vessel remaining as simple engines. To show how numerous and important in many cases these auxiliary engines are, those of the Trafalgar, now building at Portsmouth, may be mentioned. There are altogether in this vessel, besides the main propelling engines, fifty auxiliary steam engines, with no less than 119 separate steam cylinders, and they would, if worked altogether, be capable of exerting more than 5,000 indicated horse power. Of course they would not be worked all at the same time in practice, and many of them work only for very short periods. A detailed list of these engines with the power of each is annexed, the list being arranged in ascending order of power of one engine.

The engines for working the dynamo machines were the first of these auxiliary engines in which the compound system was introduced. They are so in several vessels now in commission. In a few recent cases, in addition, the large hydraulic pumping engines are made compound, while still more recently the principle has been extended and applied to many other auxiliary engines where it could be conveniently done. The first vessel for which this has been arranged is the torpedo depot ship Vulcan, where, besides the engines for dynamos and hydraulic pumping, the fire, bilge, workshop, feed, circulating, and other engines are to be of the compound type. A considerable saving of fuel may be expected as the result of these changes among the small engines, and much has been realized already in the case of the dynamos, where the consumption of fuel has been very considerably reduced, which is, I think, to a very large extent due to the action of the Admiralty in instituting consumption trials, and placing a specified pecuniary value on reduction in steam consumption, which is taken account of with the price in the consideration of tenders. This has stimulated a wholesome rivalry between the various makers with very beneficial results, the records of trials showing that the consumption of coal per electrical horse power has been reduced during the last four years by at least thirty-five per cent. with the same type of dynamo and engine.

H. M. S. TRAFALGAR.

*List and Power of Auxiliary Steam Engines.*

| Engines. | No. in Ship. | No. of Cylinders to each. | Estimated I. H. P. Each. | Estimated I. H. P. Total. |
|---|---|---|---|---|
| Workshop | 1 | 2 | 3 | 3 |
| Drain tank pumping | 2 | 1 | 3 | 6 |
| Ash hoists | 2 | 2 | 10 | 20 |
| Auxiliary circulating | 2 | 1 | 12·5 | 25 |
| Auxiliary hydraulic pumping | 1 | 2 | 16 | 16 |
| Distilling condenser | 2 | 2 | 17 | 34 |
| Bilge engines | 4 | 2 | 20 | 80 |
| Starting | 2 | 2 | 25 | 50 |
| Turning | 2 | 2 | 25 | 50 |
| Exhaust ventilating fans | 3 | 3 | 40 | 120 |
| Pressure ventilating fans | 4 | 3 | 40 | 160 |
| Forced draught fans | 6 | 3 | 45 | 270 |
| Main feed pumps | 2 | 3 | 60 | 120 |
| Auxiliary feed pumps | 2 | 2 | 60 | 120 |
| Fire engines | 2 | 2 | 60 | 120 |
| Air compressing | 2 | 2 | 62 | 124 |
| Electric lighting* | 3 | 4 | 80 | 240 |
| Steering | 1 | 2 | 122 | 122 |
| Main condenser circulating | 4 | 1 | 140 | 560 |
| Boat hoisting | 2 | 2 | 280 | 560 |
| Capstan | 1 | 2 | 400 | 400 |
| Hydraulic pumping* | 2 | 4 | 1,000 | 2,000 |

* Denotes compound engines.

| | |
|---|---|
| Total No. of engines | 50 |
| Total No. of cylinders | 119 |
| Total I. H. P. | 5,200 |

One great object of the various increments that have been made in the working steam pressure, and the changes of type of engine, has always been the reduction of consumption of fuel for a given power, so as to enable a smaller weight of coal carried in the bunkers to be sufficient for steaming a certain distance. Many of the changes made with this object in view have tended directly to increase the weight of the machinery, but, notwithstanding this, a noteworthy feature of the machinery of the last few years is the great reduction that has been made in its weight per horse power, which reduction, when coupled with the large saving in fuel, owing to the increased economy of the engine, has enabled the speed of many of our recent ships to be largely increased. Although the fastest vessel of size yet tried is the Rattlesnake, with a measured mile speed of about nineteen knots, the estimated speed of many vessels now being built considerably exceeds twenty knots. Twenty knots is the estimated speed of the Medea class to be tried this year, and of the torpedo depot ship Vulcan. It is also to be practically the speed of the Barham and Bellona. The seven torpedo gunboats of the Sharpshooter class will have a speed of twenty-one knots, while in the first class cruisers Blake and Blenheim the speed will be twenty-two knots, all at their load draught. Our knowledge of the resistance of the various forms of vessels at different speeds is now much more complete than it used to be, so that it is anticipated with confidence that these designed speeds will not only be attained, but possibly exceeded when proper screws have been determined.

In the navy, for many years past, great attention has been paid to this question of reducing the weight of machinery, which in a war vessel is always of the first importance, and some very successful results have been obtained in this direction. The gradual reduction which has taken place in the weight of the propelling machinery is exhibited in the following table, where the weights are given for a series of representative vessels from the date of the introduction of the screw down to the present time. The vessels are divided into three groups of simple, ordinary compound, and triple expansion type, and it will be noticed that the first engines fitted on the compound and on the triple expansion principle are rather heavier than the last of the type immediately preceding.

*Screw Propelling Engines.*

| Ship. | Date of trial. | Load on safety valves. | I.H.P. | Revolutions per minute. | Piston speed per minute. | Weight per I.H.P. | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Engines. | Boilers. | Total. | |
| | | lbs. | | | feet. | lbs. | lbs. | lbs. | |
| Himalaya | 1854 | 15 | 2,046 | 56 | 392 | 183 | 282 | 465 | Early screw vessel, simple engines, and jet condenser. |
| Agincourt | 1864 | 25 | 5,913 | 53 | 426 | 153 | 213 | 366 | Simple engine and jet condenser. |
| Swiftsure | 1869 | 30 | 4,913 | 68 | 647 | 148 | 152 | 300 | Simple engine and surface condenser. |
| Alexandra | 1875 | 60 | 8,498 | 66 | 528 | 175 | 173 | 348 | Early compound engine. |
| Phaeton | 1884 | 90 | 5,588 | 100·2 | 801 | 135 | 185 | 320 | Later compound engine with ordinary draught. |
| Scout | 1885 | 120 | 3,370 | 153 | 760 | 78 | 116 | 194 | Compound engine with forced draught. |
| Mersey | 1886 | 110 | 6,628 | 123·5 | 805 | 82 | 103 | 185 | Compound engine with forced draught. |
| Galatea | 1887 | 140 | 9,219 | 114 | 836 | 87 | 105 | 192 | Triple expansion engine, forced draught. |
| Victoria[1] | 1888 | 135 | 14,200 | 100 | 850 | 80 | 93 | 173 | Triple expansion engine, forced draught. |
| Medea[1] | .. | 155 | 9,000 | 140 | 910 | 71 | 85 | 156 | Triple expansion engine, forced draught. |
| Sharpshooter class[1] | .. | 155 | 4,500 | 310 | 1,060 | 30 | 52 | 82 | Triple expansion engine, forced draught. Modified torpedo-boat type. |

[1] Weights as specified.

The Medea may be taken as representing the latest practice as regards the machinery of fast vessels, where the special features of the torpedo boat type are not adopted. Her machinery will weigh 630 tons for 9,000 I. H. P., or at the rate of 156 lb. per I. H. P. The weight of the machinery of the Sharpshooter class is given for comparison, and it shows that with this modified torpedo boat type, the weight of machinery is only about one-half that for the Medea type. The table also shows the progressive increase that has taken place in the working pressures of steam and in the piston speeds of the engines.

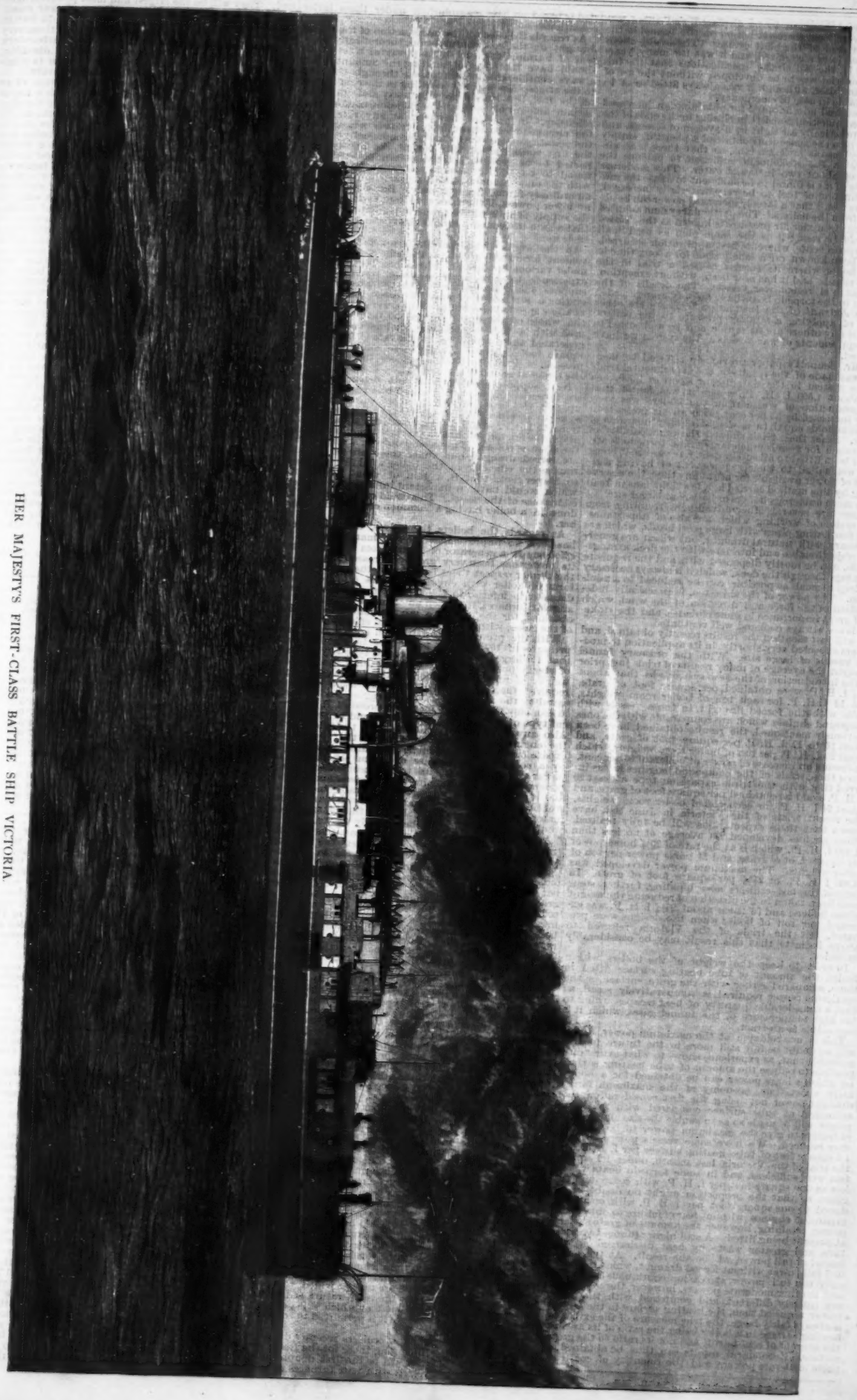
In the other part of the total propelling apparatus, viz., the weight of coal required to be carried for steaming a certain distance, as the result of the increased efficiency due to the use of high steam pressures and the improved type of engine, very considerable reductions have also been made. In the days of the first engines fitted to naval vessels, such for example as in the old paddle wheel vessels Salamander and Rhadamanthus, in 1832, the consumption of coal with their low pressure of 4 lb. per sq. in., and no expansion, was about 8 lb. per hour per I. H. P. This was gradually reduced, till in 1859 the consumption of the newest engines of that date, say, for example, the old screw vessel Galatea, with the increased steam pressure of 22 lb., was about 5 lb. per I. H. P., both these vessels having the jet condenser. The adoption of the surface condenser came soon after this, the pressure of steam still rising, and as a later example we may take the Thunderer, tried in 1872 with surface condensers, an increased steam pressure of 30 lb., and a fair amount of expansion carried out in the cylinders. Her consumption at ordinary cruising speeds may be taken at about 3¼ lb. per I. H. P. per hour. All the preceding vessels have simple engines. In the compound engines which came immediately after the date of the Thunderer's trial, the consumption of coal was again greatly reduced, due to the combined effects of an increased steam pressure and the compound system. The consumption in these at cruising speeds may be taken at 2¼ lb. per I. H. P. per hour, while by the increase of steam pressure to 150 lb. per square inch, and the adoption of the triple expansion engine, the consumption of fuel has been brought down to about 1¾ lb. per I. H. P. per hour.

As examples showing clearly what these reductions of weight of machinery and consumption of coal mean as regards enabling the offensive and defensive powers of war vessels to be increased, the effect on such armorclads as the Thunderer and Superb, if they were to be refitted with modern machinery instead of that at present on board, may be mentioned.

In the Thunderer the present machinery consists of a set of simple low pressure engines of about 6,000 I. H. P., the weight of machinery being about 1,010 tons, coal carried 1,350 tons, giving the vessel a coal endurance of 17½ days at 10 knots. Supposing new machinery of the triple expansion type to be fitted, with the increased power of 7,000 horses, and a working steam pressure of 150 lb., the weight of the new machinery would only be about 730 tons, so that the saving of weight effected under this head would be about 280 tons. Also, as the consumption of fuel with the new machinery would be only about one-half that with the present, the same radius of action would be secured by carrying only about 700 tons of coal, thus effecting an additional saving on coal for the same radius of action of over 600 tons. The total saving of weight, therefore, for the whole propelling apparatus would be nearly 900 tons, with which a considerable addition could be made to the efficiency of the vessel.

In the case of the Superb, which has a set of old low pressure simple engines of about 6,500 I. H. P., with a weight of 1,140 tons, new machinery of the triple expansion type, with an increased power of say 8,500 horses, could be fitted, at a weight of only 840 tons, so that a reduction could be effected of 300 tons, and with the new engines the distance the vessel could steam with a certain quantity of coal would be doubled. In such cases as these, too, the saving in cost of fuel per annum would be considerable.

Mentioning next the boilers, the most important development that has taken place is the adoption of the plan of increasing the rate of combustion in the furnaces usually known as the "forced draught." The practice of forcing the fires by artificial means beyond the rate given by a chimney has been very common in the past. For many years the "steam blast" was always fitted to naval boilers for this purpose, a jet of boiler steam being injected at the base of the funnel, which by its rapid expansion displaced the funnel gases and caused an increased flow of air through the fires. This was a very simple plan, but there are several objections to it—the loss of fresh water from the boilers which this plan involves is in these days of high pressure steam inadmissible; it was also very wasteful of fuel, as the steam acted directly on and in contact with



HER MAJESTY'S FIRST-CLASS BATTLE SHIP VICTORIA.

the body of the gases to be displaced, and there was often severe local corrosive action on the funnel in the neighborhood of the blast orifices. These objections have been long recognized, and it was for many years inserted in the Admiralty specifications that the full power on trial was to be developed without the use of the steam blast, although it was always fitted so as to be available in case of emergency.

The method now adopted for obtaining an increased rate of combustion consists in closing in the ends of the boilers practically air tight by a system of screens, and forcing into the space thus obtained a plentiful supply of air by means of steam fans, so that there is an air-pressure in the stokeholds sufficient to balance the weight of about two inches of water. This moderate pressure of air is found to be sufficient to cause the rate of combustion of fuel to be very materially increased, with the result that a largely increased power can be obtained from the boilers. The particular system adopted for working under air pressure is known as the "*closed stokehold*" system; it is the same plan as used in all our torpedo boats, where its first application occurred. It has been known on a small scale for a long time in these boats, where its success caused a trial in the larger vessels, and it has now been, without exception, adopted in all recent war vessels. The details of the system in the torpedo boats have already been recorded in the *Journal* of the Institution.* There are other plans of applying air under pressure to the boilers, but not any others are so simple and so well suited to the requirements of war vessels as the system we have adopted.

In Mr. Sennett's paper previously referred to, mention was made of the results of the experimental trials of the system in the Satellite, a sloop of 1,500 tons and about 1,500 I. H. P., where it was found that the production of steam from the boilers was very easily increased by 55 per cent. with an air pressure in the stokeholds equal to a weight of only one inch of water. Since these trials showed the practicability of the system for vessels much larger than torpedo boats, it has been fitted to all subsequent war vessels, it being very well suited to their requirement of having a reserve of power available for use at any time, the reserve being by this method carried in a few light fans instead of in more numerous boilers or boilers of larger size.

There are several other advantages resulting from this system of working which are also of importance. The ventilating pipes with large cowl heads, which are necessary with natural draught, but which are generally objectionable and interfere with the deck arrangements, can be mostly dispensed with, and the requisite openings through the deck, which it is always necessary to keep as small as possible, can be reduced to a minimum. The power of the ship, too, is practically independent of the force and direction of the wind, which is of great importance in some climates, and the stokeholds are always cool and well ventilated.

I will just mention the results recently obtained, and others expected very shortly, in its application to modern vessels of large size. With the ordinary funnel draught the average of many results of trials just prior to the introduction of the new system was that about 10¼ I. H. P. were obtained per square foot of grate, and 12 I. H. P. for each ton of boiler room weights, while with the forced draught, in those vessels with compound engines which are comparable with the ones previously mentioned, the results obtained have been about 16 to 17 I. H. P. per square foot of grate, and about 20 I. H. P. per ton of boiler room weights, which represents an increase of power of boilers of 66 per cent. From these trials of the compound engines it was inferred that with the triple expansion type at least 20 I. H. P. could be obtained per square foot of grate, and about 24 I. H. P. for each ton of boiler room weights. The recent trials of the Victoria, in June last, have shown that these expectations will be fully realized. These engines developed an average of no less than 14,200 I. H. P., which is at the rate of 20½ horse power per square foot of grate, and 24 horse power per ton of boiler weights. The maximum power developed was 14,800 I. H. P., or 21½ per square foot of grate. In some of the fast cruisers now building, further steps have been taken in the direction of reducing the weight of the boilers, and in these about 26¼ I. H. P. was expected per ton of boiler when the designs were prepared, but the trials of the Victoria referred to above indicate that this result may be considerably exceeded.

In order to keep the weight of the boilers within limits, the amount of tube heating surface fitted in them, compared either with the grate surface or the maximum power required, is comparatively small, so that a considerable quantity of heat escapes, owing to the high temperature of the funnel gases, which it is impossible to abstract.

This is unavoidable at the maximum power, and it will no doubt be felt still more in the future, for it is probable that, as experience shows to what extent it is possible to reduce the amount of tube heating surface by which a large power can be obtained for a moderately short time, economy at the maximum forced draught power not being the first consideration, this reduction of tube surface compared with the horse power will be made so as to enable the size and weight of boilers to give the maximum power to be still further reduced. We have some vessels now with only 1·3 square feet of tube heating surface per I. H. P.; on the trial of the Victoria last month, under 1·2 square feet were sufficient, and in some torpedo boats it is as low as one square foot per I. H. P. with compound engines, so that the proportion might no doubt be reduced to one square foot per I. H. P. with our triple expansion engines, without fear of failure to obtain the power, retaining, however, the amount of grate surface at present being fitted. A still higher funnel temperature, and greater waste by heat discharged up the funnel at full power, will be the result. At the specified full power without forced draught, which is practically the full power at sea for continuous steaming, and at other moderate powers, however, the conditions are entirely different, and compared with the horse power required then, the heating surface in the boilers is always fairly large, the true measure of the extent of heating surface in a boiler being the ratio of its area to the amount of coal burnt, and not its ratio to the grate surface. Economical results can thus be obtained at these moderate powers, and the quantity of coal carried is based on the consumption under these latter conditions.

As regards the effect of the introduction of the forced draught on the coal consumption, theoretically a system of burning the fuel by a powerful blast of air should have the effect of limiting the amount of air, always considerable, which passes through the fires to the atmosphere without assisting in the combustion of the fuel, but simply carrying away and wasting a certain amount of heat, and is therefore conducive to efficiency. In practice, however, at any rate, under the circumstances attending full power trials, where the *quantity* of coal burnt fairly economically must be the first consideration, this benefit can hardly be expected to be realized, and the consumption of fuel is found to be about the same as it would be in boilers with the same amount of heating surface if worked by an ordinary funnel draught only. But when working at lower powers, if the fans were kept running so that the supply of air could be properly regulated, we know that a gain in economy should be experienced through their use.

In the works of the late Professor Rankine, a convenient formula is given for the efficiency of a boiler under various conditions, which has been found by experience to give fairly accurate results. Let us suppose one boiler of the Medea being used for generating a low power of only 560 horses when cruising at a low speed, instead of the full power of 2,250 horses, the whole of the grate surface of that boiler being used with a very slow rate of combustion, the power generated then would be at the rate of 5 I.H.P. per square foot of grate. Under these conditions the expression of Professor Rankine places the efficiency of the boiler at about 79 per cent.

Next suppose that only the two center fires of the six furnaces are used, the wing furnaces being closed up, and the fans allowed to run at a moderate speed so as to produce the same power. Under these conditions 15 I.H.P. would be generated per square foot of grate, the amount of heating surface being practically the same as before. This would only be a very moderate forced draught, but under these altered circumstances the efficiency of the boiler would be increased to 86 per cent., that is, a gain of about 9 per cent., which would have an important influence on the coal endurance of the vessel. This could of course only be done in a boiler having a common combustion chamber.

As regards the boilers themselves, however, there has been no improvement for very many years in its *efficiency* as a generator of steam from coal, although its power has been very greatly increased; in fact, in the former respect there is no doubt that the present form of boiler with circular furnaces often of small diameter is inferior to the old type with roomy rectangular furnaces, in which much more space could be obtained for the intimate mixture and combination of the gases, with a resulting gain in efficiency.

With the present triple expansion engine and steam pressures of 150 to 160 lb. per square inch, it is certain that for large boilers of the present type any increase of steam pressure would result in an increased total weight of machinery, owing to the increased weight required for the boilers being more than would be saved by the reduction in size of engine, and the gain in economy through the increased pressure, if the present type of engine were retained, would be very small. Also any endeavor to again increase the efficiency of the engine by changing the type to the "quadruple expansion" would be of little use unless accompanied by a considerable increase of steam pressure. The power of modern vessels has to be concentrated in large boilers, owing to the limitations of space and weight, and it appears as if no very considerable increase of working pressure were practicable with our present materials and type, for the shells of these large boilers would become too thick to be properly worked.

Another feature of the last few years has been the trial again of what is generally called the *tubulous* boiler, in which the steam is generated by the hot gases in contact with a series of tubes only with the omission of the shell, furnaces, and combustion chamber of the ordinary boiler. This type of boiler offers great facilities for obtaining safely any increase of pressure that is likely to be wanted, the water being inside small tubes, and the material distributed in the best possible form for resisting the pressure. Large numbers of so-called tubulous boilers have been designed, but the working of most of them has not been very successful, especially in the mercantile marine; lately, however, they have been used with more success than formerly. We have in the past learned much from the makers of torpedo boats, and a successful example of this type of boiler was fitted on our second class torpedo boat No. 100 by Messrs. Thornycroft & Co., tried in 1886, and has since given satisfactory results. Similar boilers have been fitted on some foreign torpedo boats, and three of the first class torpedo boats now being built for the Indian marine are also being fitted with it. Messrs. Yarrow have also designed and tried at their works a form of tubulous boiler which promises to be successful, but it has not as yet been fitted to any vessels.

I do not suppose that tubulous boilers will soon be fitted to our larger vessels with the present pressures, especially where several would be required, on account of the difficulties in working these boilers in combination; there is, in fact, no necessity for them at present; but it appears that if any considerable increase of pressure be desired, some such form may become indispensable. In the French navy, a similar form of boiler on the Belleville principle has been fitted to some cruisers, and so far as is known, has given satisfactory results.

In our new vessels, double-ended boilers are now used both for economy of weight and saving of space. These are necessarily very long, and with the high temperature of steam now used, any considerable differences of temperature between the various parts of the boiler lead to unequal expansion and severe strains, and for this reason all such boilers are now provided with feed water heaters, which raise the temperature of the feed water considerably from that at which it is delivered from the condensers, before it is permitted to enter the boiler.

All the boilers for the fast cruisers recently designed are on this principle, including those for the Blake and Blenheim. These latter will be the first double-ended boilers fitted in our vessels with four furnaces at each end. They will be the largest and most powerful boilers we have, each of them generating sufficient steam for 3,350 I. H. P.; their dimensions are over 15 feet in diameter and 18 feet long, and to prevent these very large boilers being used for the ordinary harbor work of the vessel, such as for electric lighting, distilling, and drill purposes, an auxiliary boiler with two furnaces is fitted in one of the boiler compartments.

In connection with the boilers, the adoption of an important fitting may be mentioned, which is a sequel to the surface condenser, and an extension of the same principle. This fitting is what is known as the double distillation condenser. The adoption of the surface condenser caused the main body of the boiler feed water to be changed from salt to fresh, but a certain percentage of the feed water being always lost during its transit through the engine, this deficit of feed water was, until very recently, made up by sea water, the scale from which at the high temperature of the steam is left in the boiler. When distilling fresh water for drinking purposes also, with the old form of distiller, a large quantity of scale was unavoidably deposited in the distilling boiler. With the modern marine boiler, however, this occurrence is most objectionable, and to obviate it, the particular form of distiller mentioned has been adopted, in which the evaporation takes place in an intermediate vessel between the boiler and the fresh water condenser, and in this intermediate evaporator the scale is deposited, the arrangements being such that it can be properly cleaned out and dealt with. The generation of steam in the evaporator is caused by the condensation of steam from the main boiler in or around tubes, and this condensed steam is returned to the boiler. By this means, nearly all the scale will be kept out of the main boilers, a supply of fresh water being obtained sufficient to make up the loss which occurs when cruising at ordinary speeds.

One of the principal points to be attended to in the design of engines for modern war ships is the fact that while they have to be capable of obtaining a high maximum speed when required, yet most of their steaming is done at much lower speeds, and at powers very often less than one-tenth of the maximum, and the engines must be capable of working economically at these low powers, or else the coal required is seriously affected. The disproportion between the maximum power and the power required for ordinary cruising has become of late very great, and as showing how the limits of power between which the same set of machinery has to work well have been constantly widening, the following examples are given, going no further back than about ten years:

*Table showing the Ratio of Full Power to Ordinary Cruising Power.*

| Ship. | Date of Trial. | Displacement. | Full Power. | Full Speed. | Per cent. of full power required at 10 knots |
|---|---|---|---|---|---|
| | | tons. | horses. | knots | |
| Temeraire | 1877 | 8,540 | 7,520 | 14·6 | 28 |
| Iris | 1877 | 3,730 | 7,330 | 18·0 | 18 |
| Inflexible | 1878 | 11,880 | 8,010 | 13·8 | 33 |
| Nelson | 1878 | 7,630 | 6,640 | 14·0 | 31 |
| Amphion | 1884 | 4,300 | 5,500 | 16·5 | 19 |
| Mersey | 1885 | 4,050 | 6,000 | 17·0 | 16 |
| Curlew | 1886 | 950 | 1,500 | 14·5 | 28 |
| Archers | 1886 | 1,770 | 3,500 | 17·0 | 19 |
| Grasshoppers | 1887 | 525 | 3,000 | 19·0 | 13 |
| Victoria | 1888 | 10,470 | 14,200 | 17·25 | 12 |
| Sharpshooters | not yet tried | 735 | 4,500 | 21·0 | 10 |
| Vulcan | not yet tried | 6,620 | 12,000 | 20·0 | 8 |
| Medea class | not yet tried | 2,800 | 9,000 | 20·0 | 7 |
| Blake | not yet tried | | 9,000 | 20,000 | 22·0 | 6½ |

In the Blake and Blenheim, first-class protected cruisers, of 9,000 tons and 22 knots speed, now building, the maximum power being very large, namely, 20,000 horses, while the power required for the 10 knot speed is only about 1,300 horses, or 6½ per cent. of the maximum, a decision has been come to which will greatly increase the efficiency of their engines at low speeds. In these ships four sets of triple expansion engines will be fitted, two sets on each of the twin screw shafts, and to secure minute subdivision and protection of the vessel, these four are in separate engine rooms. The forward sets of engines on each shaft are arranged so that they can be disconnected from the after sets, and at low powers only the after engines will be worked, and one-half the constant friction of the engines removed altogether; under these circumstances the speed of the vessel would be about 16 or 17 knots, while as regards further reduction of power and speed to those which would be used on ordinary occasions, the ship will be under far more favorable conditions than would have been the case had the maximum power of 20,000 horses been developed by two sets of engines only.

An important point as regards the arrangement of the engine should be next described. The old paddle wheel engines being to a large extent necessarily exposed to the risk of damage in action, the vertical engine was generally used for these; but when the screw propeller was introduced, and it became possible to have the whole of the machinery protected, the vertical engine was abandoned, and the horizontal type was invariably used for many years. In those few early screw vessels in which engines of similar speed to those of paddle engines were fitted, with gearing to obtain the increased number of revolutions of the screw, the vertical engine still remained, but these were very few in number, and, as before mentioned, the natural plan of running the engine at the same number of revolutions as the propeller was soon adopted. From this date, about 1850, the horizontal engine has an unbroken record in large fighting vessels for about twenty-five years, all vessels of this class being fitted with them, till we come to the Alexandra, Dreadnought, and Temeraire, designed about 1873, in which cases the vertical engine was introduced, and these were the first large fighting vessels so fitted since the days of the old paddle wheels. The disadvantages of the horizontal position are that the pistons and reciprocating parts are of great weight, and borne to a large extent by the rubbing surfaces of the piston and cylinder, so that great wear takes place at the part where it is of the greatest

* See *Journal*, vol. xxv., No. 111. 1881.

importance to retain an accurate and perfectly steam-tight joint, and this must cause loss after the engine has been running for some time, by the direct passage of steam past the piston when worn. In the modern engines on the triple expansion principle this action certainly occasions loss in a much less degree than with the old simple engines, but the vertical position is the most natural for an engine. It avoids this uneven wear of cylinders, all its parts are more accessible for examination and repair, and the engine can be kept in an efficient condition much more readily than if horizontal. The weight of the pistons and other reciprocating parts in this case are taken at the main bearings, which are constructed especially for such work. These advantages of the vertical engine and others, such as facilitating the water-tight subdivision of the vessel, caused them to be fitted in the Alexandra, Dreadnought, and Temeraire, the cylinders being efficiently protected by the side armor fitted.

Since its introduction into these vessels the vertical engine has, without exception, been fitted in all first class battle ships, and in the first class cruisers. One noteworthy feature of naval engineering in recent years is this more extended use of the vertical engine, a step which has been of great importance in adding to the prolonged efficiency of the propelling machinery, especially of those high speed vessels now becoming so general. During the last year or two a further important step in this direction has been taken by fitting vertical engines in the Medea and Medusa, second class cruisers of 20 knots speed, commenced in 1887, they having been up to that time excluded from the vessels of the cruiser class, except the largest. Since this time it has been very generally introduced into most recent vessels of that class, and it cannot be questioned that the efficiency and durability of the propeller engines of these vessels have by this means been materially increased.

There are many other interesting points in connection with the machinery which I have not been able to mention within the limits of this paper, and of those portions I have described, I cannot hope to have given more than an imperfect review.—*Jour. Royal United Service Institution.*

## A FAST STEAM LAUNCH.

THE illustrations show a steam launch of peculiar dimensions lately built by Messrs. Cochran, steam yacht and launch builders of Birkenhead. This launch is 50 ft. long by 11 ft. beam and is 4 ft. deep. She is designed not to draw more than 2 ft. with a full complement of fifty passengers. The general arrangement is clearly shown by the plan and elevation, and is as follows: The machinery is placed amidships; forward there is a large open space for passengers with seats all round, and aft also a large space for passengers, similarly fitted with seats.

The launch is built of steel plates ⅛ in. thick, and the frames are proportional in scantlings. Although the dimensions seem light, yet they are abundantly strong enough for the purpose for which the boat is intended, viz., passenger traffic on inland waters in India, and afford a good instance of the great advantages which steel gives for the construction of light draught vessels. The launch is fitted with powerful steering gear forward, by means of a teak wheel with handsome brass mountings. There is also a windlass worked by hand, and an anchor and chain.

The machinery consists of two single-crank engines driving twin-screws, each engine having one cylinder 7½ in. in diameter by 8 in. stroke. The engines are made with large bearings and other working parts adapted for high speeds. The boiler is of the locomotive type, with a very large furnace to burn wood or any kind of inferior fuel, and extra large heating surface. This vessel on her trial attained a speed of almost 13 miles an hour on a draught of water under 2 ft., and the builders have no doubt that after running a short time she will show even better results.—*Engineering.*

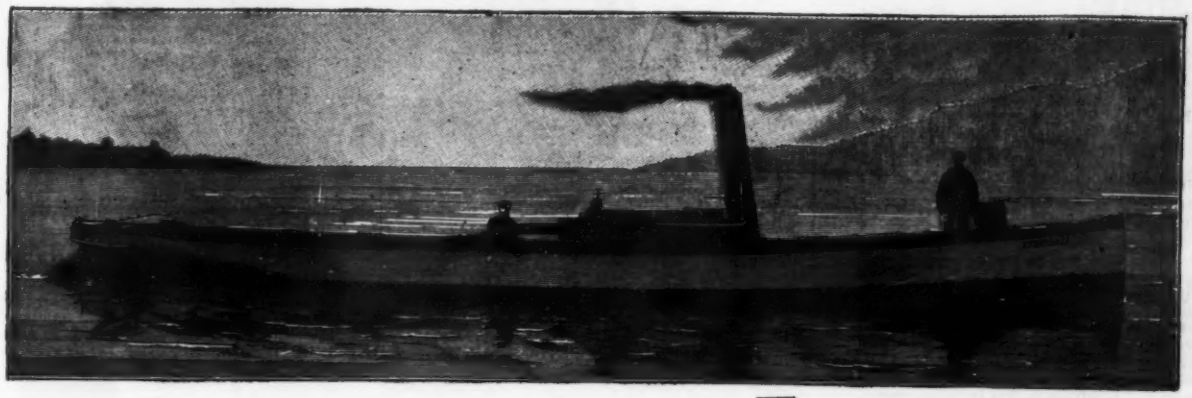


Fig. 1.

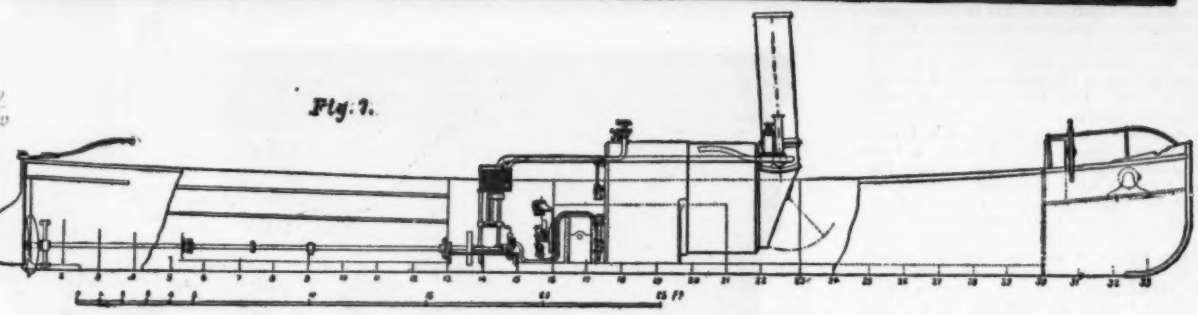
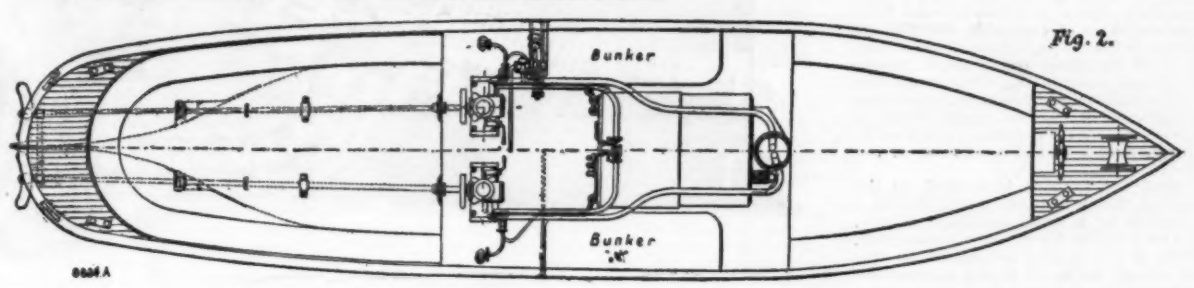


Fig. 2.



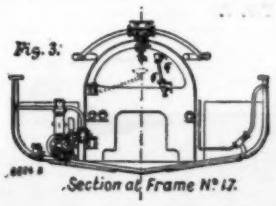



Fig. 3. Section at Frame N° 17.

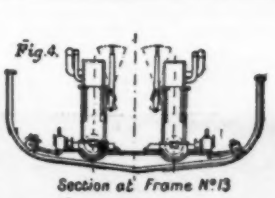


Fig. 4. Section at Frame N° 13

## THE STEAM LAUNCH VICTORIA.

## LA GUAIRA HARBOR.

THE official opening of La Guaira harbor, Venezuela, took place on February 9, the ceremony having been performed by his Excellency the President of the republic. We now give some particulars of the works and of their construction under Mr. J. L. Houston, the chief engineer. We may premise that the geographical situation of La Guaira is 10° 36′ N. and 67° 2′ W. of Greenwich meridian. The average temperature is 27° Cent., and the distance of La Guaira in a straight line from Caracas is 5¼ miles, by the cart road 21½ miles, and by the railway 23¼ miles. The population of the town is about 7,000. The town was founded in 1588 by its governor, Don Diego de Osorio Villegas, on the site named by the Caribs, Huaira. The bay of La Guaira is on the Atlantic, and is the only available port for the capital. The government, on May 21, 1885, contracted with Messrs. Punchard, MacTaggart, Lowther & Co., of London, for the construction of a harbor for the accommodation of the existing trade, and also to serve for its future development. The work of construction occupied three years. The main feature is the breakwater, which is built with enormous blocks and masses of concrete to a finished width of about 33 feet, at 13 feet above the level of the sea, and crowned by a parapet 13 feet high. The breakwater, when finished, will have a length of 2,050 feet, of which 1,456 feet have already been partly constructed. The method of the construction of this superstructure is as follows:

The concrete is put into iron wagons, which are conveyed by a locomotive to a steam crane near the point of the advancing wall. This crane places the concrete into a depositor, by which sack blocks of 72 tons are formed and dropped on to the lower foundation, constructed with floating depositors. When three or four tiers of these 72 ton blocks have been brought up to the water level, the same machinery and plant serve to build the final capping of concrete, inside a timber framing. The 72 ton depositor is a novel apparatus designed specially for this work by Mr. W. C. Punchard, Assoc. M.I.C.E. It is an enormous wagon, running on six lines of rails and balanced, so that when a sack has been filled and laced up, by releasing its catches the mass is slowly dropped exactly in the required position, and the empty wagon recovers its original position.

The foundations of the breakwater are also built by concrete sack blocks of from 120 to 150 tons weight each. These are formed in large floating depositors, which are towed out and moored, and the blocks dropped into the required position. By this means an artificial reef is formed about 56 feet wide and of an average height of 30 feet. The breakwater, when finished, will be provided on its harbor side with two extensive wharves for the largest class of steamers. At its extremity a lighthouse will be erected with a powerful light. On the right hand side of the lines conveying concrete to the 72-ton depositor there is another line of rails by which wagons of large stones are brought in and thrown on the outer side of the shore end of the breakwater. No less than 15,000 cubic yards of bowlders have been deposited here, and form an artificial foreshore by which the force of the waves is broken. This bank of stone extends about 263 feet from the shore. The breakwater and quays now inclose a surface of about 6½ acres of embankment. From the breakwater the east quay commences, running in a southwesterly direction, nearly 2,000 feet, in a straight line. Of this, a length 1,050 feet have been completed.

We will now describe the main concrete mixing station and its arrangements by which the floating depositors are filled. Shingle is stored in a central depot, for the foundations and the superstructure. The main mixing platform is a raised timber structure with three steam mixers, a centrifugal pump and tanks for wetting the concrete, and a cement hoist worked by an endless chain. The shingle is filled from the deposit into specially constructed wagons, which, when loaded, are pushed up, three at a time, by a locomotive, and the contents are tipped into hoppers communicating with the mixing cylinders. From an elevated road is tipped, simultaneously with each wagon of shingle, a small Decauville wagon of cement. A pipe from the water tanks supplies to each mixer the necessary quantity of water, and the revolving machine mixes all the materials thoroughly together. The concrete slides into the floating depositor by iron shoots. An enormous sack fits into a well in the depositor, the hinged doors at the bottom of which are suspended at each end by a system of rods and catches, which, when relieved, drop the bag instantly. The concrete mixing apparatus has turned out over 700 tons of concrete daily.

The next feature of interest is the new Resguardo basin, a small dock formed under the shelter of a part of the east quay, the shore wall being a stone pitched slope, from which various jetties and wharves are projected. There are two entrances, one being intended principally for the passage of the iron concrete depositors, and the other for general harbor traffic by lighters and small vessels; several steamers have already occupied berths in this basin. The wharves have a length

of 800 feet, and an average depth of water of 13 feet; they are equipped with a system of railways in connection with the La Guaira and Caracas Railway, two large warehouses, three 3-ton and one 8-ton steam cranes. For the finished port, besides the east quay, there will be two iron jetties constructed, running parallel with the breakwater. These will accommodate steamers of the largest class.

At the east quay, which is at present in course of construction, the system of building is first to drive two rows of piles which, with crossheads and beams, forms a stage upon which a concrete depositing wagons runs, similar in construction, but much smaller than that for the breakwater. The lower part of the wall is brought up in 12-ton sack blocks, and the upper part from four to five feet under water in concrete formed inside framing. As this wall proceeds the embankment is carried on behind it, and the land reclaimed forming wide and convenient quays, as well as for all harbor purposes. There are two systems of drainage to convey the sewage of the town out to sea, and which is a great desideratum in La Guaira. There is plenty of reclaimed level ground for all purposes, the property of the harbor corporation. Up to the end of last year 98,925 casks of cement had been used in the manufacture of over 70,000 cubic yards of concrete. The contractors employ over 800 men, and have at work seven locomotives, six steam and two hand cranes, four portable engines, besides a complete general equipment for a work of this description. When completed, the new harbor works will have 2,050 feet of breakwater, 5,422 feet of wharves, with from 12 to 30 feet of water, 19 acres of land round quays, seven warehouses, with a gross capacity of 451,243 cubic feet, 2¾ miles of railways, besides fresh water supply, lighting, numerous steam cranes up to 12 tons, locomotives, wagons, offices, steam tug, and lighters.

## A SMOKE CONSUMING FURNACE.

THIS furnace, which is the invention of Mr. Lewis Hopcraft, is a distinct departure from the usual practice in this direction. It is a revolving furnace of circular form, self-feeding, self-maintaining, and self-discharging, only slack or small coal being used. The principle is that known as underfeeding—the fuel being supplied to the fire from underneath the furnace grate—in conjunction with a mechanically induced or forced draught. It is to an automatic and continuous supply of fuel and air in the requisite proportions, together with the mechanical action of the furnace, that its satisfactory working is due. The fuel, which is small coal, is charged into the hopper in front of the furnace, which latter is inclosed on account of the forced draught. From the bottom of the hopper a tube rises with a gentle curve to the under side of the furnace. Inside this tube is an ingenious vertebrated Archimedean screw, by which the coal is slowly fed upward into the center of the body of incandescent fuel on the grate, the screw being revolved by worm wheel gearing. The grate, which is driven through chain gearing, consists of concentric rings of cast iron, with air spaces between them, and it slowly revolves on its axis, which is inclined toward the bridge at a slight angle. A supplementary grate is fitted beyond this, and receives and automatically discharges the clinker which is continuously delivered on to it by the circular grate. The inclination thus given to the grate beneficially directs the radiant heat of the fire toward the heating surface of the boiler, and promotes the uniform and constant distribution of the fuel, which tends to fall toward the lower level and is gradually elevated to the higher level in the course of the revolution of the grate.

We have said that the furnace is worked on the forced draught system, which draught is supplied by a Sturtevant fan driven by a small auxiliary engine, which also drives the gearing for revolving the grate, the speed of which is about one revolution in five minutes. The air supply being in direct communication with and controlled by the coal feed, the relative proportion of air to coal remains practically constant, whether 10 lb. or 40 lb. of coal are being consumed per square foot of grate surface per hour. In operation, the coal, as stated, is delivered upward into the body of incandescent fuel on the grate, on nearing which a distillatory or gas generating process is effected. The products of distillation—otherwise the smoke-producing constituents of the coal—having to pass up through the incandescent fuel on the grate, become highly heated, and, meeting with the streams of atmospheric air which are also being forced through the incandescent fuel on the grate, ignite, producing brilliant flame. The residue of coke is burned on the grate, and forms the incandescent fuel which renders the process constant and regular so long as the furnace is at work, and so long as coal and air are supplied in due proportions. This being the process by which fuel is burned in the Hopcraft furnace, it is obvious that large coal—which always contains a considerable proportion of small—may also be burned in this furnace to great advantage as compared with the ordinary method. The small coal becomes as valuable for steam raising as the large, thus raising the efficiency of the whole, while it is at once evident that for ships of war burning the rich semi-bituminous and smoke-making Welsh coal the smokelessness of this furnace is a feature of great importance. The fact, too, that this furnace admits of skilled stokers being dispensed with will be appreciated by steam users generally. In the run with the Lotus, the fuel used was slack, and, although the furnaces were in no way forced, steam was not only well kept, but was blowing off. There was no smoke, except for a few minutes when Mr. Hopcraft was requested to demonstrate that he was using a bituminous and not a smokeless coal. This he did by shutting off the forced draught, when imperfect combustion soon made itself known by the smoke which issued from the funnel. The engineer in charge informed us that he had no trouble whatever with the furnace, but always kept steam well. With regard to the saving effected, the managing director of the Victoria Company, Mr. Williams, stated that the tests made by the officials of the company before and after the Hopcraft furnace was fitted to the Lotus proved that slack could be burned without smoke, and at a saving of from forty to fifty per cent., the engines indicating the same horse power as when best Welsh coal was used, under the continuous action of a steam blast in the funnel.

The general advantages of the Hopcraft furnace may be briefly summarized under three heads, namely, the saving in the cost of fuel which is effected through being able to burn small coal and coal dust, the absence of all smoke, and the reduction in the item of stokers' wages. That these advantages have been fully and rapidly recognized is evidenced by the fact to which we have previously alluded, namely, that the adoption of the furnace in a number of steamships has already been determined upon. The success of the furnace on board the Lotus has led to the Victoria Steamboat Association giving orders for it to be fitted in eight more of their vessels. Beyond this we are informed that orders are also to hand from several parts of Great Britain, amounting in the aggregate to upward of one hundred furnaces. We can but congratulate Mr. Hopcraft upon the scientific success of his invention, and the company upon the promise the furnace gives of proving a commercial success.—*Iron.*

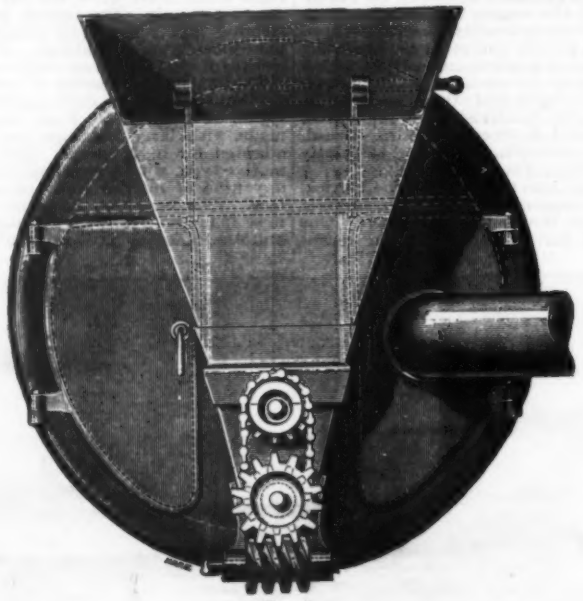


FIG. 1.

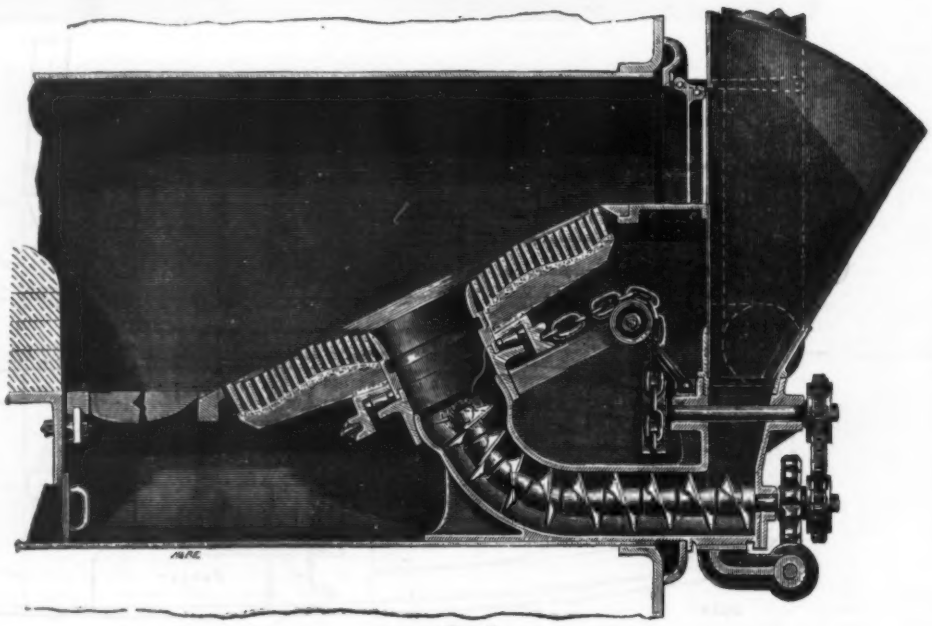


FIG. 2.

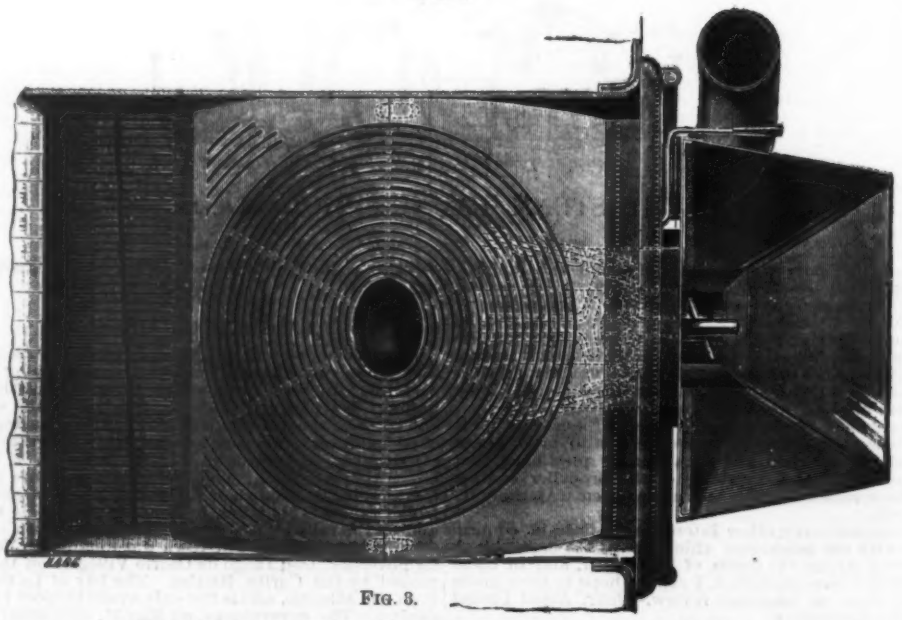


FIG. 3.

IMPROVED SMOKE CONSUMING FURNACE.

## LIQUID FUEL.*

By M. J. FRANCISCO.

AT the present time we have no knowledge of any means of securing light without heat, and it only remains for us to employ the most economical fuel to produce the heat without useless waste. It has been asserted that the question of dividends in electric lighting lies between the shovel and the dynamo, and the fraternity have been taxed to their utmost to provide a plan for dispensing with the shovel entirely, and thus securing at least a part of the much coveted dividend. Petroleum, it is claimed, will furnish the substitute. Query, Will it? One pound of coal contains 12,000 heat units, while one pound of petroleum furnishes 20,000. Another factor of vital importance is the power to

* A paper lately read before the National Electric Light Association, Chicago.

vaporize water. Engineers of experience who are familiar with the practical workings of coal know that under the most favorable conditions not more than ten pounds of water can be vaporized per pound of coal, while petroleum shows a vaporization of eighteen pounds of water for every pound of oil consumed, estimating in both experiments the feed water at 212 degrees Fahrenheit. The heat in coal transferable to water is about 70 per cent., while the heat in petroleum transferable to water is about 80 per cent. Therefore, with coal 70 per cent. of 12,000 units gives 8,400, and for petroleum 80 per cent. of 20,000 is 16,000, a gain of 7,600 heat units in each pound. This is on the basis of pure coal; but when we consider the waste, amounting in some cases to 25 per cent.—and the master mechanic of one of the largest railroads in the country claims 55 per cent.—found in nearly all coal, such as sulphur, slate, and earthy substances which are incombustible and retard instead of generating heat, the difference in the per cent. obtained in actual practice is far greater than shown by the above comparison. There is also in coal a large percentage of loss in transportation, and combustion in the heap, varying from 5 to 10 per cent. From these facts we can safely conclude that the heating capacity of oil is nearly twice that of coal as generally used.

On this basis the only question to be considered is the cost of power furnished by each at the dynamo. Three and one-half barrels, or 955 pounds of oil, equal 2,240 pounds of pure coal, therefore with oil at $1 per barrel and coal at $3.50 per ton, or oil at $1.50 per barrel and coal $4.50, the difference in cost would not be so marked, if there were no other factors to be considered. When, however, we calculate the great saving in stoking, removing cinders and ashes, cleaning flues and benefit to boilers, besides securing a steady heat, combined with the quickness and ease in starting and shutting down, we have an argument in favor of oil that stockholders who care for dividends can appreciate. I have found, upon investigation, that oil can be delivered at my station for $1.05 per barrel, while soft coal costs $4.50 and hard $6 per ton. On this basis, allowing five pounds of coal per hour, twelve hours per day, 1,000 horse power requiring 803 tons per month at $4.50 would cost $3,613.50; two firemen to feed the same, $100; man cleaning flues, etc., $45; carting ashes and cinders, $10); making total cost for thirty days $3,858.50 with coal. The same number of horse power and same length of time, allowing three and one-half barrels for each ton of coal, would require 2,810 barrels of oil at $1.05. This would equal $2,950.50. Wages of one man in boiler room, $50, making total of cost of 1,000 horse power one month, with oil, $3,000.50, showing a saving of $858 per month, in above item, besides getting with oil a steady flow of steam, thereby producing that great consideration, regularity of speed. This is absolutely necessary in order to produce a perfect light, and will save in addition the wear and tear of the manager's nerves, as, fluttering and jumping in unison with the spasmodic light, he stretches the third commandment to its utmost capacity. If you are now burning coal, it will be necessary to equip your station with tanks, burners, cylinders, oil pumps, compressors, air receivers, and additional apparatus, varying according to the number and size of boilers used.

During the past few months the following facts have been gleaned from an extensive correspondence on this subject with parties who are using liquid fuel. The Boston & Albany Railroad Company, after a careful test made in their shops by a Lehigh University professor, say that the cost of fuel is about the same. Though they purchase their coal in large quantities at one time and secure low rates, they prefer liquid fuel, because it is clean and requires no fireman, and gives a better supply of steam. Day Cordage & Co., of Boston, claim that with Cumberland coal at $4.50 per ton, and liquid fuel at $1.15 per barrel, they save 15 cents per 100 horse power per hour, and the oil is preferable. The Fairbanks Scale Company, of Vermont, report that they find it a great saving over coal, while the boilers are heated evenly the entire length, also that the insurance companies have not increased their rates. T. P. Brown, manager of the Toledo, Columbus & Southern Railway, reports a saving of 33 per cent. of the price of coal, by using liquid fuel, also that two barrels of oil equal one ton of soft coal, while manufacturers on his road find it only costs one-half as much as coal for their stationary boilers. The Rolling Mill Works, of this city (Chicago), use it under a battery of fourteen boilers, and say that three and six-tenths barrels of oil does the work of one ton of coal. The cost of oil is less than coal, but the great saving is in labor for stoking, wheeling ashes, and unloading coal. Formerly, when using coal, twenty-five men were required to operate this battery of boilers for twenty-four hours; now, with liquid fuel, four men accomplish the same work. The efficiency of the boilers is increased and cost of repairs lessened, while oil flame is less severe upon the boilers.

Reference could be made, if necessary, to hundreds of persons who have had practical experience in burning oil, fully sustaining the facts given above, proving conclusively that liquid fuel is at least one-third cheaper than coal, and it is destined to be the fuel of the future.

I have thus far shown the benefits to be derived by using liquid fuel. It is, however, necessary to consider many points before deciding to adopt it, especially if your plant is in the center of a large city with other property in close proximity. Managers of insurance companies are just cranky enough to believe that oil will burn, and unreasonable enough to object to your exposing and destroying property for which they have to pay, thus burying their dividends in the same pit you are trying to avoid. Therefore they insist upon certain conditions before they consent to its use. Among other things, that you store your oil 50 or 100 feet away from your station. If this should happen to place your oil tank adjacent to your neighbor's property, you will have the officers of the insurance companies whose policies cover his buildings operating in a way that will drive grounds, short circuits, and underground wires out of your minds for a month. If necessary precautions are taken, and the apparatus is properly and securely arranged, there is no more danger with liquid fuel than coal. In fact, it may be made safer, and insurance companies will permit its use without an extra charge for the privilege. Examine carefully, however, from an insurance standpoint, any apparatus offered you, before attempting to use it, or you may find that insurance is an expensive luxury, and operates fully as disastrously upon dividends as coal.

An iron tank will be required for storage of oil, which should be located under ground 100 feet from your station. This tank, if sixteen feet in diameter and eight feet in height, will hold 950 barrels. If twenty feet in diameter and fourteen feet in height, 600 barrels. A pipe from this must pass under ground to the car for unloading the oil by gravity, if practical; if not, by pumping. A second iron tank, holding enough oil for one day's use only, can be placed immediately outside the boiler house, with a safety pipe one and one-half inches in diameter extending ten feet into the air, to permit the escape of gas. This tank must be connected with a large tank by an underground pipe for the purpose of forcing the oil into the smaller one, with another pipe for an overflow to carry the oil back or away, in case the pump is neglected or left running.

The small tank must be lower than the burners or furnace, so that in case of accident the oil will flow back to the tank. In all pipes there must be stopcocks that will cut off communication between the burners and tank. The supply pipe at the boilers should be arranged with a valve not over one-half inch in diameter, so that oil cannot, under any circumstances, be forced under the boilers faster than same is consumed by the burners; thus preventing an overflow from flooding the firebox. There must also be an escape pipe extending outside the building for cleaning the tubes. In no case must the oil be allowed to flow from the tank to the burners by gravity, but must be supplied either by vacuum process, steam, or compressed air. For this there are several plans: One is to force steam across the opening of a vertical pipe from the tank, and thus draw the oil up to the mouth of the furnace. Another is to use compressed air for atomizing the oil, and passing it to the burners. Others still use a retort and generate a gas. Unless the apparatus used is expressly arranged for starting the fire, oil must not be turned on until the burners are heated, for if it is, flashes and explosions will follow. If a station is furnished according to above conditions, the insurance companies will insure it without extra charge. If not, they will demand from 50 cents to $2 extra for every $100 insured, according to any deficiency that may exist, while if the burners are fed by gravity, it is a prohibited risk.

Faraday has stated that the chemical action of a grain of water upon four grains of zinc can evolve electricity equal in quantity to that of a powerful thunderstorm. The Springfield Electric Light Company found by a practical experiment, made last December, that a small quantity of petroleum under certain conditions could evolve a sufficient amount of flame to annihilate an electric light station without any thunderstorm. They placed a storage tank, holding 160 barrels, in the basement of the main building, and another in the boiler house, containing the supply for daily use. From the last tank the oil was carried to the fires by gravity, and here was the cause of the fire. Having received a fresh supply of oil, they filled the large tank under the building, then turned the oil into the small tank in the boiler room, and left the pump working, while the men were busy in another part of the station. It overflowed the tank, and the oil escaped into the furnace, with the usual results following from gravity pressure, less oil, less building, and less lights, with insurance managers running wild over the hazard of electric light buildings. Is it any wonder insurance companies object to assuming such hazards?

Holmes has said that "Science is a first-rate piece of furniture for a man's upper chamber, if he has common sense on the ground floor," but if he has not got plenty of good common sense, the more science or more liquid fuel he has, the worse for him. An electric light station can be made just as safe and secure as any mercantile risk, and insured at the same rate.

It behooves the members of this association to investigate this subject, and correct the errors of the past, if they do not wish all electric light plants placed upon the prohibited list. For why should the most powerful and magnificent system for the protection of mankind, known as insurance, and the youngest child of science, electric light, appear as antagonists upon the world's arena?

Now, gentlemen of the National Electric Light Association, as there is no State in the United States, and few counties, that have not a town called "Franklin," so in the not distant future there shall not be a city, village, or hamlet where the current which leaped to earth at his command shall not be utilized in that most wonderful invention of modern science, the electric light—an invention which is daily fulfilling Goethe's last prophetic cry, "More light! more light!"

## PHOTOGRAPHIC CHEMICALS AND THEIR IMPURITIES.

AMONG the many chemicals used in photography, the alkaline salts are the most important and often contain the greatest quantity of impurities. A number of these impurities are incidental to the processes by which the salts are manufactured, and not being easily eliminated in the course of purification, may cause very serious trouble when used for photographic purposes. Taking sodium carbonate as the first, and, perhaps, most useful alkaline salt in the process of development, let us stop a moment to consider the several processes by which it is made, and the impurities it is likely to contain.

There are three processes from which the sodium carbonate of the American market may be obtained. The first of these is the old Leblanc process; the second, the Solvay or ammonia-soda process; and third, the cryolite process of the Pennsylvania Salt Company.

It is probable that most of the soda crystals are made from products produced by the Leblanc soda process, as practiced in England. Without going into details, this process consists in first converting sodium chloride (common salt) into sodium sulphate by the aid of sulphuric acid; then, by roasting this sodium sulphate with coal and limestone, the sulphate is converted into sodium carbonate ("crude soda ash," as it is called); this last product after crystallizing gives us the soda crystals of commerce. The sources of the impurities in this method of manufacture are numerous. The common salt used for the purpose is reasonably pure; at least the impurities are generally only lime and magnesium salts, which do no harm as far as photography is concerned. But as soon as the sulphuric acid is added, we begin to introduce a number of impurities. This acid as made in England often contains arsenic and nitrous compounds, which, when brought into contact with the sodium chloride, forms compounds with it that are by no means easily eliminated from the subsequent products. When we remember the exceedingly minute quantities of material that affect the photographic image, we are constrained to believe that the traces of arsenic often found in soda crystals may have some important effect upon photographic results. Yet the quantity of arsenic is exceedingly small in even the crude soda crystals, and possibly its presence is unimportant; nevertheless it is very active in its reactions, and may have an influence far exceeding our expectations. But this is not the most important impurity in soda crystals. The most serious trouble comes from the impurities introduced during the conversion of the sodium sulphate into carbonate by roasting with coal and limestone. Having made this roasting, the crude semi-fused mass is treated with water, which dissolves the sodium carbonate formed, and gives the liquors from which the sodium carbonate crystals are ultimately obtained. An examination of these liquors reveals the fact that, in addition to the sodium carbonate which they contain, there is also present sulphite, hyposulphite, sulphide, and cyanide of sodium. It is obvious that unless the sodium carbonate is crystallized several times, traces of all these compounds find their way into the crystals. Their effect upon the photographic work done with such crystals is the more dangerous according to their amount.

It is too true that there is much crude soda crystals in use that contain considerable quantities of sodium sulphate. This impurity is harmless, but is an index of imperfect purification, and such crystals should not be used for photographic purposes. If one impurity is present in large amount, it is reasonable to suppose that others of more importance, and not as easily eliminated, are also present.

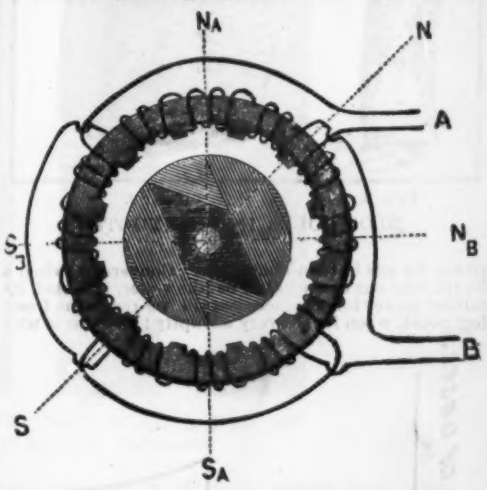
Fortunately we are not confined to the use of soda crystals, and there are two products in the American market that are admirably fitted for photographic use. Only they must be used with judgment. These products are the sodium carbonate made from cryolite and a like product made from common salt by the ammonia process.

The first of these is perhaps the purest commercial sodium carbonate made, its only impurities being traces of alumina and lime. In using it, remember that it is dry sodium carbonate without any water of crystallization; consequently, only about thirty-seven per cent. of the weight given for the crystals should be used.

The sodium carbonate made by the ammonia process is perfectly free from the dangerous impurities incidental to the Leblanc process; but it contains two products that result from its method of manufacture. One of these is ammonia salts and the other is an excess of carbonic acid. Dry sodium carbonate made by the ammonia process often gives a faint odor of ammonia, due to the volatilization of the ammonic carbonate which it contains. The presence of the excess of carbonic acid in this last variety of sodium carbonate is due to the imperfect heating of the sodium bicarbonate, which is one of the steps in the process of manufacture. There is no particular harmful influence exerted by this excess of carbonic acid, but it makes it very difficult to determine the true strength of the material. It is almost impossible to know how much real sodium carbonate there is in such a product, the sodium bicarbonate being of little use as a developing agent.—*Anthony's Photographic Bulletin.*

## THE TESLA MOTOR.

ALTHOUGH the theory of the Tesla motor is now so widely known—though doubtless better known than understood—yet the practical construction of the apparatus has not yet been explained. The following brief description will therefore be read with interest. The field magnet consists of a laminated ring, with internal projections like Paccinotti teeth. It is wound with two independent circuits, A and B; in the motor from which the diagram is taken there are twelve sections in all, and the two coils are wound upon every three sections alternately. The three sections on the right of the figure, and the three on the left, the two being joined in series, form circuit A. Similarly, the three upper and the three lower sections form circuit B. The resultant fields of each coil independently are shown by the lines $N_A S_A$, $N_B S_B$, respectively. But the currents in these two circuits are relatively displaced by ¼ phase. Thus, when the current in A is at a maximum, the current in B is at zero, and the resultant field for both coils passes through $N_A S_A$; so, also, when B is at a maximum and A is at zero, the resultant is $N_B S_B$. But when the two currents are equal, the resultant passes through the line N S; the direction of the resultant is, of course, reversed at the moment when the two currents are equal in value but opposite in direction. The armature is drum-wound, with four



coils, as shown, each being short-circuited on itself. The resultant axis passes through N S.—*The Electrician.*

## SIBLEY COLLEGE LECTURES.—1888-89.

BY THE CORNELL UNIVERSITY NON-RESIDENT LECTURERS IN MECHANICAL ENGINEERING.

### III.—THE HEAT-TREATMENT OF STEEL.

By HENRY M. HOWE, of Boston, Mass.

IN this lecture we will study the effect of heat-treatment on what I am sometimes tempted to regard as the most wonderful of substances, iron. By heat-treatment, I mean exposure to certain high temperatures and to certain changes of high temperature. When I speak of iron, I speak generically, including both wrought iron and steel.

If we examine a simple, unforged casting of steel, such as a common pyramidal steel ingot, we find that it is anything but homogeneous. It contains cracks and cavities, its composition varies from point to point, and, even when the composition is uniform, the structure or grain varies greatly. Let us consider separately these three forms of heterogeneousness—cracks and cavities, heterogeneous composition, heterogeneous grain.

*Cracks and Cavities.*—To understand the origin of these, we must bear in mind that the ingot is formed by pouring a mass of molten steel, extremely hot, into

FIG. 1.—BLOWHOLES IN STEEL INGOTS.

a relatively cold cast iron mould. During the solidification of this molten mass, our cracks and cavities arise. They are of two chief classes. First we have wormlike or lenticular cavities (Figs. 1 to 3), which are due to the escape of gas during solidification. It was formerly thought that these tubules in steel were formed by the escape of carbonic oxide gas, generated by a chemical reaction between carbon and oxygen contained in the molten metal, for all, or nearly all, steel, as you doubtless know, contains more or less carbon. But later examination has proved that they are in large part formed by the escape of hydrogen and nitrogen previously dissolved in the metal.

As the temperature of a solid rises, the solubility of gas diminishes; then, when the solid is melted, its solvent power for gas increases enormously and abruptly. When the resulting liquid is further heated, its solvent

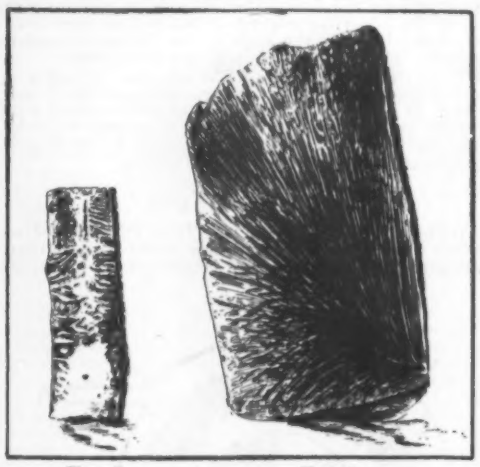


FIG. 3. FIG. 2.

BLOWHOLES IN ICE INGOTS.

power for gas in turn diminishes. Conversely, when a liquid, like our molten steel or like water, is cooled, its solvent power for gas increases till we reach the freezing point, when it falls very abruptly; and this is why

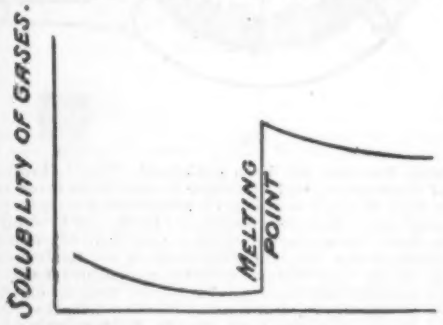



*Fig. 4.*

CONJECTURED CURVE OF SOLUBILITY OF GASES IN IRON.

and water expel gas, which forms blowholes or les during solidification or freezing. (See Fig. 4.)

The chief reason for believing that the blowholes are formed by hydrogen and nitrogen escaping from solution, and not by carbonic oxide formed by chemical reaction within the metal, is that the gases which escape from the surface of the metal before and during solidification, and those which are present within the tubules of the solidified cold metal, when collected, are found to consist chiefly of hydrogen and nitrogen. Those in the blowholes in the cold solidified metal indeed consist practically solely of these two gases. Beyond this, gases escape and blowholes form in iron in which it is extremely improbable that carbonic oxide should form, both in metal free from carbon and in that free from oxygen. Finally, a vast array of cumulative evidence shows that the behavior of the gases which escape from molten and solidifying steel is that of previously dissolved gas, and not that of a gas formed by chemical reaction at the time of its escape.

Leaving the blowholes, we next notice a large central cavity, due to uneven contraction. As the cast iron mould into which the molten steel is poured is much colder than the steel itself, and as iron is a rather poor conductor of heat, the outer shell of the ingot freezes and cools to a considerable extent while the

FIG. 5.—PIPE IN BESSEMER STEEL RAIL INGOTS.

center is still molten. At any given instant during the early part of the solidification, the inside of the ingot is considerably hotter than the outside. In the further cooling which occurs after this instant, therefore, the inside must cool through a greater range of temperature than the outside, and must, therefore, contract more. As the inside is united firmly to the outside, the excess of the contraction of the inside must give rise to an empty space. This is known as the pipe. (See Fig. 5.)

Similar cavities are seen in castings of glass rapidly solidified, for instance the Prince Rupert's drops.

If an ingot be thrown on its side during cooling, the pipe moves to the position shown in Fig. 6.

FIG. 6.—PIPE IN OVERTURNED AND INVERTED INGOTS.

In addition to these blowholes and pipes, the ingot is liable to have cracks, and sometimes quite deep ones, on its outside. These are sometimes due to the fact that, during the *early part* of the freezing, the skin of the ingot cools faster than the interior, and, therefore, tends to contract faster. The slowly cooling interior opposes the contraction of the skin, which thus becomes tightly drawn, and perhaps so tightly as to crack. In other cases these outside cracks are due to roughness of the mould. The molten steel flows around these roughnesses and dovetails itself into them. As it solidifies, these dovetailings hold it fast here and there to the mould, and in its effort to contract during subsequent cooling, the skin of the ingot is torn.

The next feature of heterogeneousness which we come to is segregation. When a supersaturated solution of some salt, say copper sulphate or blue vitriol, is cooled, it deposits crystals, and these crystals are much purer than the solution from which they separate. If our solution contains besides copper sulphate some other salt, say sodium chloride, the crystals of copper sulphate will be relatively free from sodium chloride, and this latter salt will gradually accumulate in the remaining solution or mother liquor. A somewhat similar action occurs in a solidifying steel ingot. Crystals of steel may be said to be deposited by the molten mass on the sides of the ingot mould, and these crystals tend to expel the impurities, such as phosphorus and sulphur, present in the molten mass. These impurities thus expelled then concentrate in the portion of the ingot which remains molten longest, or, rather, which freezes last. This region, in a common ingot, is found near its top, and here we find these impurities concentrated. If our ingot be drawn out into a rail, and if we polish and etch sections of this rail at three points corresponding to the top, the middle, and the bottom of the ingot, we will often get the appearances shown in Fig. 7. The bottom section is nearly homogeneous, the middle one is less so, while the top one is extremely heterogeneous, showing the presence of different strata which are differently acted on by the acid. If matters be so arranged that the lower part of the ingot solidifies later than the upper part, then these impurities seem to collect rather in the bottom of the ingot.

SECTION FROM TOP. SECTION FROM MIDDLE. SECTION FROM BOTTOM.

FIG. 7.—SEGREGATION AT DIFFERENT POINTS IN THE LENGTH OF A RAIL INGOT DEVELOPED BY ETCHING THE SURFACE OF A CROSS SECTION. (Emmerton.)

The forms of heterogeneousness which we have considered up to this point cannot be remedied by heat-treatment alone. The cracks and cavities can be closed only by mechanical means. The segregation of impurities can be rendered somewhat less hurtful by forging the ingot, so as to draw the segregated matter out into a long rod, instead of leaving it as a solid bunch.

There is, however, another form of heterogeneousness, the coarse grained structure of the ingot, and this can be almost wholly removed simply by heat, without forging or any form of mechanical treatment.

The structure of the ingot is not simply coarsely crystalline, but differently crystalline in its different parts. Toward the outside we have well marked columnar crystals, similar to the basaltic columns of the Giant's Causeway and of similar masses. (See Fig. 8.)

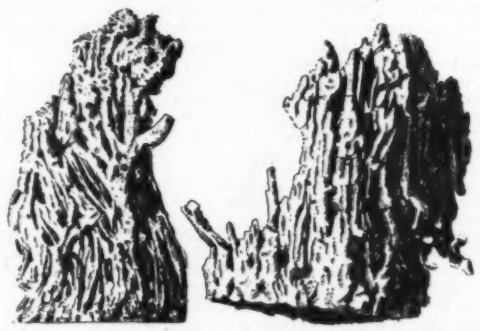


FIG. 8.—COLUMNAR CRYSTALS FROM STEEL INGOTS.

These columns are always perpendicular to the cooling surface, and they can be induced in a great many solidifying masses. Many metallurgical slags habitually crystallize in this way in strongly marked columns, normal to the cooling surface, and I have often induced this structure in ice formed under certain conditions. But these columnar crystals extend in only a certain distance, being abruptly succeeded by nearly or perhaps quite equiaxed ones. Now, this coarse crystalline structure is a source, or, at least, a concomitant, of weakness. Be the reason what it may, it is a fact that, in steel and iron, as in many other substances, the strength and toughness, the general fitness for engineering purposes, are, roughly speaking, inversely proportional to the coarseness of grain. It is with the coarseness of grain and the way in which it is influenced by heat-treatment that we will concern ourselves during the remainder of this lecture. Unfortunately, our knowledge of the laws which govern the size or coarseness of grain is extremely imperfect, so imperfect that I should not venture to treat of them were it not that I regard the subject as of the very greatest moment, and that I believe that an increase in our knowledge of it, such as we can doubtless get by more study and observation, would be of enormous advantage to engineers, and, through them, to mankind.

You will please regard what I am now going on to say, not as final, but as simply an attempt to lay before you certain laws imperfectly deduced from very imperfect and sometimes even contradictory data.

As I have already said, the coarse crystals of steel ingots and other steel castings may, by simple heat-treatment, be almost wholly obliterated.

This is exemplified by the series of pieces of steel which I now lay before you. These pieces originally constituted a bar of steel which, throughout its length, was coarse-grained, soft, and brittle. It was cut from an unforged steel casting. One end of the bar was heated to a white heat, the other end remaining cool, and the temperature gradually declining as we pass from the white hot toward the cool end. The bar was next removed from the fire and allowed to cool slowly. It was then broken into short fragments, the fracture of each of which reveals the size of the grain of the metal at a certain point in the length of the bar. You will note that the pieces broken from the end of the

bar which was white hot, *i. e.*, from the hot end, have a finer grain than those broken from the end which was not heated, *i. e.*, the cool end. The latter shows us the grain which the ingot possessed before undergoing heat-treatment. On fitting together the fragments you will further note that, while those from the cool end of the bar have broken apart without bending appreciably, those from the hot end have evidently bent much before breaking. The metal at the hot end of the bar is clearly very different from that at the cool end.

Something which occurred during heating or during cooling, or both, has changed it from coarse to fine, from brittle to tough, without materially changing its hardness proper. This change probably occurs during heating, because, if we cool the bar suddenly instead of slowly, we find that the portion which had been highly heated is still fine-grained.

Now, if we examine the different parts of this bar, we find that, starting from the cool and proceeding toward the hot end, comparatively little change in the size of the grain occurs till we reach a certain point, when the grain suddenly becomes finer, and the metal tougher. As we pass still farther toward the hot end, the grain again becomes somewhat coarser, and the metal somewhat less tough, but it remains much tougher and finer grained than the cool and unchanged end. This teaches us that, in heating our bar, a rapid change of structure and of toughness occurred as the temperature reached a certain critical point or range of temperature.

Not only is the change of structure abrupt as we pass from one part of the bar to the other, but the time required for the change from coarse to fine seems to be very short; indeed, it is possible that the change is instantaneous. On heating a chip from a coarse grained steel ingot rapidly, and immediately quenching it in water, the total time from the moment when the cold chip was placed in the fire till it entered the water being only twenty seconds, I found that the grain had become very fine, indeed, almost, if not quite, porcelanic.

This certainly seems very surprising at first, and we ask, Is it reasonable to suppose that this change occurs suddenly on reaching a critical temperature? Is there anything else in the behavior of the metal which corresponds to the suddenness of this change? We find that there is, and that a great number of the properties of iron do change critically as the temperature rises past certain critical points, and many remarkable phenomena occur.

If we stretch a steel wire by means of a gentle spring, and heat it slowly by means of an electric current or otherwise, and if we follow the expansion of the wire by means of a magnifying pointer, we note that the wire lengthens gradually as the temperature rises, till a certain critical point at a low red heat is reached, when the expansion is suddenly arrested, the wire contracts with a momentary jerk, and then re-expands. Raising the temperature still higher, we find that the regular expansion is resumed. When this jerk occurs, the rise of temperature is checked and perhaps even reversed, though the temperature ought to rise regularly and constantly, as heat is supplied to the wire regularly. It thus seems that some change occurs within the metal which absorbs a great quantity of heat. At the same time, a dry, crackling sound is heard, the thermo-electric behavior changes suddenly, the metal suddenly loses its magnetic properties, suddenly ceasing to attract a compass needle, and if, either by contact with a common magnet or by an electric current, we have made it a temporary magnet, it suddenly loses its temporary magnetism as it rises past the critical range.

This critical range at which these remarkable phenomena occur we may call V, to fix our ideas. (See Fig. 11.)

If we now raise the temperature still higher, the metal continues to expand fairly regularly, but, on reaching a certain higher temperature, about a low yellow heat, called W, a second series of phenomena occur, of which I will now notice only two.

If we support a cold steel bar on its ends within a hot furnace, and place near it a second and exactly similar bar supported over its whole length, we notice that, as the temperature of the first bar reaches a low yellow, the bar suddenly bends, then ceases bending. Something occurs as we pass this critical point W which causes the bar to bend. If we place the second bar, which has now been heated above W, on these supports, it does not bend. This seems to show conclusively that a momentary weakness occurs in the bar as its temperature rises past W which does not exist after the temperature has passed W.

But if we now take this second bar out of the furnace, and place its ends on supports in the outer air, the bar bends suddenly as it cools past the point, V, which we have already noticed. If we represent the deflections by ordinates and time by abscissæ, we get a curve like that in Fig. 9, showing that the metal remains rigid to a certain point, then deflection sets in, increases very rapidly to a maximum, again decreases rapidly, then ceases. Thirty seconds after this automatic deflection has ceased we find that the bar has regained its stiffness wonderfully, clearly showing that something which happens as the temperature sinks past V has weakened the bar momentarily. Thirty seconds after the bar, four feet long and three quarters of an inch square, has ceased bending under its own weight, you can stand on it without producing considerable further permanent set.

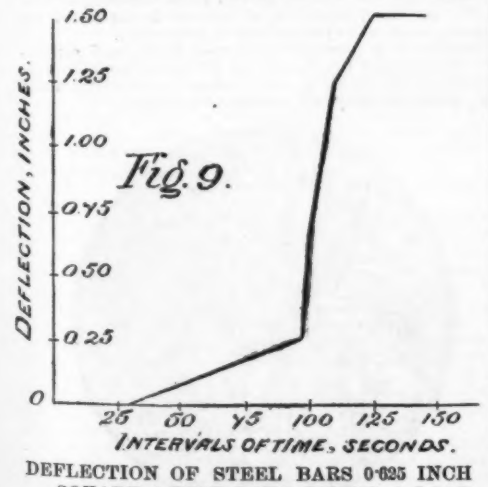


Fig. 9.

DEFLECTION OF STEEL BARS 0·625 INCH SQUARE, 4 FEET LONG, UNDER A LOAD OF 7·5 POUNDS.

I will now notice only one other phenomenon occurring at W, though I shall later refer to others. If we fit two pieces of steel together very accurately, and heat them with exclusion of air, they unite suddenly at a low yellow heat, W, though this is far below the true welding point of steel.

But as the temperature sinks from W or above past V, we get the most remarkable set of phenomena. In the case of a tightly stretched wire, the contraction, which occurs as the temperature sinks from W downward, is suddenly stopped, and the wire re-expands with a strong jerk; both heat and light are given out; the metal suddenly regains its magnetic properties. The evolution of heat, or rather of light, owing to reheating, may be seen very easily with a flat bar of tool steel. Heating one end of the bar to whiteness, and then allowing it to cool in the air, we find that a bright band suddenly appears near the junction of the glowing and the non-glowing parts, and gradually extends over the whole glowing part of the bar. This phenomenon, known as the after-glow or recalescence, is illustrated (and exaggerated) in Fig. 10.

Enough has been said to indicate that remarkable changes occur within the metal at certain critical points, V and W. Without discussing the nature of these changes, suffice it for the present to insist on the rapid change of structure, the change from coarse grain to fine, at certain critical points, during rise of temperature.

It is extremely interesting to note that the two other strongly magnetic metals, nickel and cobalt, and apparently these two only, undergo similar very marked changes. When they are heated, as the temperature reaches a certain critical range, from 220 to 440 for nickel and at about 900° C. for cobalt, there is a sudden remarkable absorption of heat, a sudden change in the thermo-electric position (at least in case of nickel), and a sudden loss of magnetism. We seem to have a veritable allotropic change, occurring at certain critical temperatures, and to have really different metals after rising above these temperatures.

Returning now to our coarse grained steel casting, let us attempt to represent graphically, by the dotted line, A E, in Fig. 11, the changes in the size of its grain with rising temperature. Let us represent temperatures by ordinates, coarseness of grain by abscissæ. We here have our two critical points, V and W, and still higher up the melting point. As the grain remains practically unchanged till the temperature nears W, so our curve representing the size of grain rises vertically to near W, then turns rapidly to the left, then again turns again to the right. We find that, as we raise the iron to higher and higher temperatures, beyond W, the fracture of the metal (observed after cooling) grows ever coarser and coarser. This is true whether we cool suddenly or slowly, so that we may extend our curve from E to F. Bear in mind that these diagrams do not aim at quantitative accuracy; they merely attempt to indicate in a rough way the results of very rough, crude observation.

It further appears that for every temperature there is a maximum size toward which the grain tends to grow; to reach the maximum size for any given temperature requires long exposure to that temperature. When the metal is suddenly heated to a temperature whose maximum size of grain is much larger than the existing grain, the grain grows at first rapidly, then more and more slowly, reaching the maximum size of grain very gradually. Let us represent the maximum size of grain for different temperatures by solid lines, like the lines, W D, in Fig. 11 and W I J in Fig. 12.

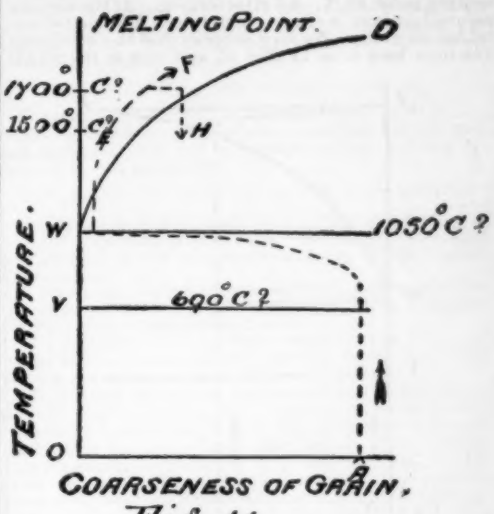


Fig. 11.

But while it appears to be a general rule that if the existing grain is smaller than the maximum for existing temperature it grows toward that maximum, if the grain is larger than the maximum for existing temperature it does not shrink back to that maximum. *E. g.*, if, having held our metal at 1,700° C. (Fig. 11) till its grain has grown nearly to the maximum for that temperature, and beyond the maximum for 1,500°, we then cool it to 1,500°, the grain does not, so far as we know, shrink back toward the maximum for 1,500°, but remains of the full size acquired at 1,700°.

As the temperature rises above W, the maximum line moves to the right, at first slowly, then very fast, till just below the melting point we have the very coarse grain corresponding to the point D of Fig. 11. This is why steel castings which in cooling have been long exposed to a temperature just below the melting point are so coarse grained.

Under usual conditions we never reheat two temperatures close to the melting point, and hence our casting when reheated does not reach the coarseness of grain which it had initially. But heating to an improper and excessively high temperature may give such a coarse grain.

In general, the rate of cooling has relatively little influence on the size of grain, because heating is usually

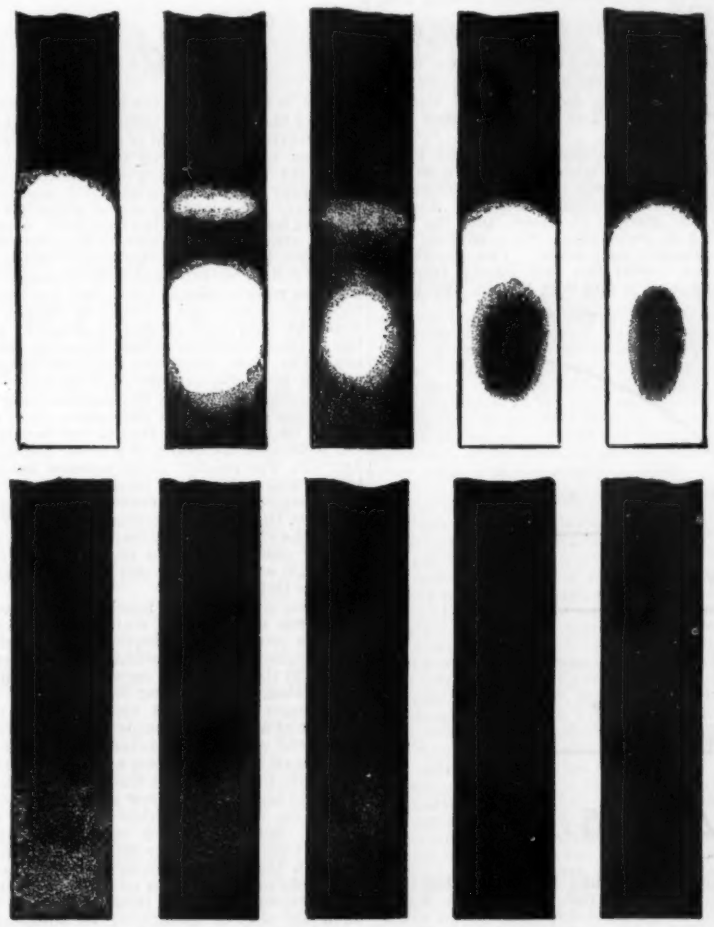


FIG. 10.—APPEARANCE DURING SLOW COOLING OF A BAR OF TOOL STEEL HEATED AT ONE END. (Brinnell.)

so slow that it gives time for the grain to grow nearly to the maximum size for the temperature reached, and there is thus little capacity for further growth during cooling. There are, however, certain exceptions to this law, and to the law that the grain if larger than the maximum for existing temperature does not shrink back to that maximum. These exceptions occur at the melting point, at W, and after forging. At the melting point all grain is, of course, obliterated. The melted metal has no grain. We may suppose that the maximum line runs back as at IJ, Fig. 12, and with it the actual

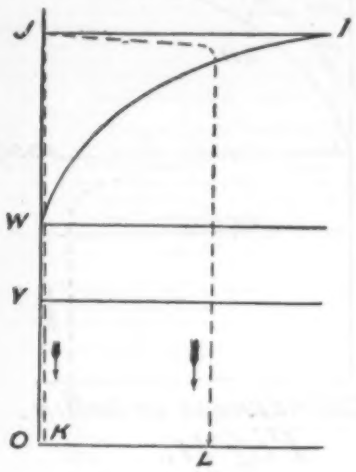



Fig. 12.

size. Now if we cool slowly from the melting point, we may suppose that the actual size of the grain increases as at JL, while if we cool suddenly the grain has no time for growth, and its growth during cooling may be represented by JK.

When the temperature rises to W, also, the maximum line recedes suddenly, as at MW, Fig. 13; and here, too, the actual size shrinks back with the maximum. Sometimes it only shrinks back part way on heating to W; then on heating again to W, it shrinks back the rest of the way. The grain becomes very fine or even porcelanic.

Since, as the temperature sinks below W the maximum line again turns to the right, so here, as in cooling from the melting point, the rate of cooling affects the size of grain, but to a much smaller extent. Sudden cooling prevents the growth of grain, and the suddenly cooled metal is porcelanic. Slow cooling permits a moderate amount of growth. The growth of the grain of pieces cooled fast and slowly from W may be represented by WN and WP, Fig. 13. But while

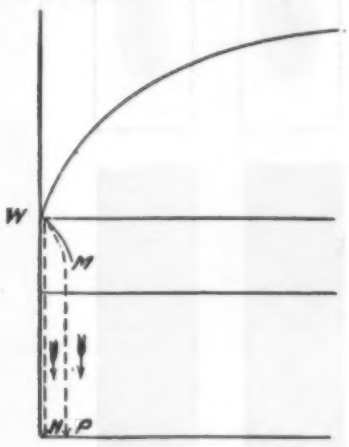



Fig. 13.

the actual size of grain shrinks back when the temperature *rises* to W, it does not, so far as we know, shrink back when the temperature *sinks* from above past W. This, indeed, is implied by the line, JL, of Fig. 12.

Now let us apply all this to the case of a steel casting. Every one will tell you that steel castings are worthless till they have been annealed; and therein every one is quite right. But there are annealings and annealings. Sometimes annealing is to accomplish one thing, sometimes another. Later in this lecture we will see where annealing is needed to remove stress and to effect what appears to be an allotropic change. Too many engineers, and metallurgists, too, have got these annealings mixed up, and, indeed, have no very definite idea what the conditions of annealing are.

In this particular case of coarse-grained steel castings, brittle because coarse-grained, our annealing aims to efface the coarseness of grain. Now, if what I have been telling you is true, to efface this it is only necessary to heat to W. If we do not heat quite to W, the coarseness is not removed; hence we must be sure to reach that point, and in order to be sure we must actually heat slightly above it. But we must bear in mind, and very many do not, that every degree that we go above W renders the metal coarser, and in so far partially undoes what our annealing has accomplished. In cooling slowly from W a certain amount of crystallization occurs; it is not great, but it is enough to injure the metal appreciably. Hence, if we want the very finest grain, we must heat to W and then cool suddenly, as by quenching in water. This, as we will soon see, leads from Scylla to Charybdis; but I will later try to point out a safe channel.

There is a third way in which the grain can be, if not effaced, at least greatly lessened, and that is by work, by hammering, or rolling, or otherwise. This breaks up the existing grain.

Let us suppose that an ingot has been heated to bright whiteness, and is to be rolled into a rail, and let us confine our attention to a point in the middle of its length. We draw the ingot from the furnace and begin to roll it. When the middle of the length of the piece gets between the rolls, the point we are considering receives a sudden squeeze and its grain is broken down, receding from A to B. Then an interval follows in which the rest of the ingot is passing through and back again before we have another squeeze. During this interval the grain is again growing, but the temperature is always falling, owing to the loss of heat by radiation, and we may suppose that the grain moves from B to C (Fig. 14). Then we get another squeeze, throwing the grain back to D, and so on.

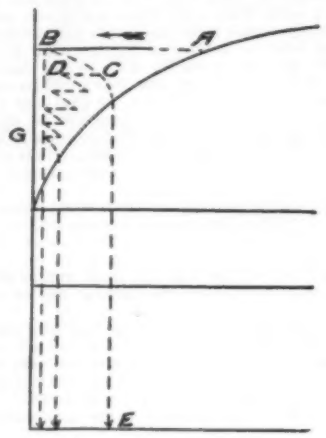



Fig. 14.

Now, it is clear that the longer we continue our rolling and the cooler the metal becomes, the less capacity for growth of grain will it have after rolling ceases.

If, for instance, rolling ceases while our metal is at the point B, then during slow cooling the path of the grain may be something like BCE, and the cooled metal may have the relatively coarse grain, OE, while if forging had been prolonged to the point, G, the grain of the metal, after cooling, would be relatively fine, OP. Now, it is well known that the smaller the section to which iron is rolled, within limits, the stronger is the metal; and the usual explanation is that the smaller piece has received more work than the larger. In case of wrought iron this greater amount of work probably has a direct beneficial effect, by more thoroughly uniting what were originally separate pieces; and work as such *may* also benefit steel directly. But we now see another reason why the smaller piece is better than the larger; the path of the larger piece may be represented by the line BE, that of the smaller, whose rolling is finished naturally at a lower temperature, by the line GP. The smaller piece, because finished at a lower temperature, has less capacity for growth of grain after forging or rolling ceases than the larger.

Again, the rate of cooling after forging ceases may affect the size of grain greatly. If we suppose that the rolling ceases when the piece is at B, in slow cooling the grain would follow the line BE, in sudden cooling the line DH.

As iron and steel are much softer at very high temperatures, say at bright whiteness, than at lower ones, we save power by employing a very high temperature for hammering and rolling them. But this always brings in the danger of excessive growth of grain during cooling, after forging has ceased. We may avoid this danger in either of two ways: we may finish the forging at a very low temperature, say between W and V, to that end perhaps interrupting the forging after it is nearly done, waiting a little till the temperature has sunk below W, and then giving a few more blows with the hammer, or a few more passes in the rolls, to break up the grain which has formed during undisturbed cooling. This is what some eye-bar makers actually do. Or we may finish our rolling or hammering at a high temperature, and then immediately immerse the metal in water or oil to hasten cooling, and thus prevent the grain from growing. But here, just as in the case of quenching or suddenly cooling our steel casting, we drive from Scylla to Charybdis. Here, too, I will try to point you to a safe channel.

Let us now consider what the specific effects of sudden cooling are. The most prominent of these, the hardening of steel, you are doubtless familiar with. Briefly, if steel containing a considerable quantity of carbon be heated to certain high temperatures and suddenly cooled, it becomes intensely hard. This operation is technically called hardening. If the hardened steel be reheated gently, and cooled either suddenly or slowly, the hardness which it has acquired is partly or even wholly removed; this operation is called tempering, *i. e.*, softening, mitigating the hardness given in hardening. The word is used in a sense similar to that in the phrase "tempering the wind to the shorn lamb." I may as well say to you at once that tempering is a form of annealing. It is much like the annealing of the metals other than iron. Copper, brass, gold, silver, if hammered cold, become brittle; they are annealed by heating, just as hardened steel is, and it makes relatively little difference whether they be cooled slowly or suddenly. The annealing is done in heating, and the species of annealing which we call tempering, the tempering of hardened steel, is also done in the heating, and hence the rate of cooling is relatively unimportant.

Let us now examine certain features of this operation of hardening.

First, let us note that steel, so far as I know, is the only metal or alloy which possesses this peculiar property in a marked degree. Further, of all the many elements which we find combined with iron, carbon alone is known to confer this property. Only iron containing carbon, that is to say carbon steel, is known to be made materially harder by sudden than by slow cooling; and the degree in which the hardness of the suddenly cooled steel excels the hardness of the slowly cooled steel increases constantly with the proportion of carbon, at least till the carbon rises to one per cent., and probably till it rises to a much larger proportion.

Let us now see what other properties, besides the hardness, are affected by the rate of cooling.

The ductility is greatly diminished, and sometimes wholly destroyed, by sudden cooling. The tensile strength is sometimes increased, sometimes decreased, according to the violence of cooling. Moderately rapid cooling increases the tensile strength. Very rapid cooling not only lowers, but may almost wholly destroy it, so that very slight stress applied from outside suffices to produce rupture. The magnetic properties are very greatly influenced. Slowly cooled steel cannot be made a strong permanent magnet; it is said to have little *coercive force*, or retentiveness of magnetism. Suddenly cooled steel, on the other hand, furnishes our magnets.

Further, just as carbon alone confers the power of hardening on steel, so the condition of that carbon in slowly cooled steel is different from that of the carbon of suddenly cooled steel; sudden cooling produces a marked change in the condition of carbon. Whether that change is chemical or physical, I will not now say; but that a change is caused is absolutely certain. The carbon in hardened steel is said to be in the hardening state; that in slowly cooled or annealed steel in the non-hardening or cement state. In both the suddenly cooled and the slowly cooled steel the carbon is combined, that is to say, it is not present as graphite, but is in some form of chemical combination. Only it is in a different state of combination in suddenly cooled hardened steel than in slowly cooled annealed steel.

Sudden cooling produces most remarkable changes in the structure of the metal, as revealed by the microscopic examinations of polished sections. We may profitably digress for a little to look at the results of microscopic study. With very high powers steel and common wrought iron are found to be, not, as usually supposed, homogeneous bodies, but to consist of different substances, which I have ventured to call minerals provisionally, till a better name is devised. These minerals are arranged much like the minerals which constitute a granite or similar crystalline rock, as is shown in Fig. 15.

Fig. 15.—MESH-WORK OF FERRITE INCLOSING KERNELS OF PEARLYTE. HALF-HARD STEEL. (Sorby.)

Besides graphite and slag, we have four important minerals, to which we will confine our attention—ferrite, cementite, pearlyte, and hardenite. These names are offered provisionally, till the true nature of these substances shall be made out better than it now is.

Ferrite appears to be nearly pure iron. It constitutes the great bulk of pure soft wrought iron.

Cementite, on the other hand, appears to be a carbide of iron, but of how definite composition we know not. It is much harder than ferrite. It or some derivative from it has been isolated, and found to scratch feldspar, but not quartz, and to have the composition $Fe_3C$. As the proportion of carbon in the metal increases, so does the proportion of cementite.

Pearlyte is a peculiar mixture of ferrite and cementite, arranged in fine bands, as if formed by paramorphism, by the splitting up of some hypothetical mineral, which we may call mother-of-pearlyte.

Fig. 16.—MESH-WORK OF CEMENTITE INCLOSING KERNELS OF PEARLYTE. HARD STEEL. (Sorby.)

In Fig. 15, we have pearlyte crystals surrounded by a mesh-work of ferrite. In Fig. 16, we have crystals of

pearlyte surrounded by a mesh-work of cementite. The latter, then, differs from the former in having cementite, the carbide of iron, for a mesh-work instead of ferrite, the pure carbonless iron; and the proportion of carbon in the whole mass of the metal is naturally much larger in the metal which has cementite than in that which has ferrite.

Now these minerals are only recognized in metal which has been slowly cooled, that is annealed. In suddenly cooled, *i. e.*, hardened, metal, we find none of them. We seem to have a single substance, corresponding to obsidian, for which I suggest the name hardenite. And it is doubtful whether the waves of light are sufficiently large to permit the ultimate structure of hardened steel to be seen. Here, then, we have a most marked change in the very nature of steel caused by sudden cooling from a high temperature.

This enables us to understand what is called the *status quo* theory of the hardening of steel. We have seen that as the temperature of the metal rises past a certain critical point, certain very marked changes occur suddenly, a great quantity of heat is absorbed, and what seems to be a new metal arises. If we cool the steel slowly, these changes are reversed as the temperature sinks back past a certain critical point, and our metal has returned to its original state. We find the properties the same as before heating.

The *status quo* theory is that the change, call it chemical or physical, allotropic or molecular, or what you will, which occurs in heating is the cause of hardening; that above certain temperatures the metal passes automatically into a new state, the hard state, *i. e.*, changes to a substance which, when cold, is intensely hard. If we cool slowly, the metal changes back from the hard to the soft state; its initial properties are regained; but this change takes time, and if we cool very fast, the metal remains in the hard state simply because the rapid cooling denies it the time necessary for the change from hard to soft. In tempering we reheat the metal gently to a range of temperatures in which the change from hard to soft can occur; *i. e.*, this gentle reheating offers the metal time to make the change which it tended to make, but had not time to make during sudden cooling. Other theories are held, but, none of them seem to me to fit the facts well enough to warrant my bringing them before you.

As the changes in the magnetic and thermo-electric properties, the crackling sound, the absorption of heat and the sudden contraction occur only as the temperature rises above certain critical points, V and W, it follows that if the sudden cooling causes hardness by preserving the new compound which is formed when these phenomena occur, then we should find that sudden cooling does not produce this remarkable hardness unless it takes place from a temperature above V and W. And this is the case.

The hardness produced by quenching is by no means a simple function of the temperature from which quenching occurs, or the quenching temperature. If we quench different pieces of steel from successively higher temperatures, the hardness of the quenched steel does not increase markedly till a certain critical temperature is reached; with slight further increase of temperature the hardness rises rapidly, apparently nearly to a maximum. To illustrate. We have here a series of pieces which were originally contiguous parts of a steel bar. This bar was heated in such a manner that the temperature declined extremely gradually from one end to the other. One end was at a full yellow heat, the other was but little below visible redness. There may have been a difference of somewhere about 600° C. in a length of 12 in., or of 50° per inch. Now when this bar had been thus heated, it was suddenly drawn and instantly quenched in cold water. Examining its hardness with the file, and passing from the cool toward the hot end, we find that the hardness does not change appreciably till we reach a point about 4 in. from the hot end; in the next inch and a half, covering possibly 150° C., the hardness rises to an apparent maximum. In certain cases I have known this to occur in a distance of ⅜ of an inch. This sudden increase of hardness occurs just where the size of the grain suddenly diminishes, that is to say at the temperature, W; and both these changes are apparently simultaneous with the change from non-hardening to hardening carbon. All through the soft part of the bar the carbon is in the non-hardening state; but just where the bar changes from soft to hard, and the grain from coarse to fine, there the carbon changes from non-hardening to hardening. I must add, however, that the coincidence of the carbon change with the hardness change and the fracture change now rests on the evidence of the nitric acid spotting test, and that we are not absolutely certain that this test gives trustworthy indications of the condition of carbon.

Whatever may be the true explanation, the fact remains that after sudden cooling we have glass hardness where we had relative softness; extreme brittleness instead of toughness; magnetic retentiveness, which we did not have before; a new condition of carbon; lower density; and, under the microscope, a single apparently homogeneous substance, where before we had a composite, granite-like mass.

There is one important effect of sudden cooling to which I have not yet referred—stress.

You are all familiar with the stress which exists in suddenly cooled glass, exemplified in the well-known toy, Prince Rupert's drop. A little molten glass is dropped in water, the outer shell solidifies and becomes comparatively cool, while the center is still molten. In cooling from this point the interior has farther to cool than the shell, and hence tends to contract more in cooling; but its rigid cohesion to the shell prevents this, and the interior remains in a state of violent tension, the exterior in a state of compression. As long as the forces are balanced, no resultant occurs. But if we destroy the balance by breaking the skin in one spot, the internal stress tears the ball to pieces.

In the case of suddenly cooled steel we have similar conditions. Sir Frederic Bramwell tells of a friend who was visiting a factory where projectiles, which had been hardened by sudden cooling, were stored. He was warned not to go into a certain shed, as those things were going off at all times, and occasionally they flew with very considerable violence. One would at first suppose that the explosion of loaded projectiles was referred to, but it was simply the cracking of the hardened shells, flying to pieces from their internal stresses, like the Prince Rupert's drop. So severe are these stresses that it is difficult to harden steel from a very high temperature without splitting or cracking it.

The stress induced by sudden cooling may readily be verified by destroying the balance of stress by eliminating part of it, as, for instance, by slitting a hardened piece longitudinally, its fragments immediately warp out of shape. A still easier way is to harden a bundle of steel strips tightly inclosed in a copper box. On drawing these strips from the box, they warp.

The stress due to sudden cooling has been thought the cause of the hardness of suddenly cooled steel. But while the stress, in a general way, increases with the hardness, there are so many apparent exceptions that the task of explaining the phenomena by stress is a very difficult one. Nevertheless, the stress induced by sudden cooling is doubtless one cause of the peculiarities of hardened steel.

We thus have two apparently distinct simultaneous effects of sudden cooling—the preservation of a hard, brittle substance formed at the critical temperature, W, and the formation of stress, which, according to its intensity, must render the metal more or less brittle, and may greatly reduce or almost destroy the strength. It may, furthermore, actually crack the metal, or greatly distort it.

On account of these effects we have not, in general, availed ourselves of the fact that sudden cooling from W preserves the fine grain set up when steel is heated to W; or of the fact that sudden cooling applied the moment that forging ceases preserves the fine grain left by forging, and prevents the growth of the grain which would take place during slow cooling after forging had ceased, the coarseness of grain our Scylla, the brittleness, and even the formation of fissures, our Charybdis. What, then, is our safe channel? At V, and at temperatures slightly below it, the metal is still sufficiently plastic to prevent severe stresses from arising. You cannot have severe stress in soft molasses candy; it yields to the stress. Further, at temperatures but slightly below V, our hardening carbon can change to non-hardening, and the hardness and brittleness which it causes can be thus removed. Finally, there is very little tendency to crystallize below V.

Our safe channel is this: If you wish to cool your steel suddenly from W, after heating it to W, so as to preserve the porcelanic grain formed at W, or if you wish to cool your steel suddenly after forging has ceased at a high temperature, so as to prevent the grain from growing coarse during slow cooling, simply do this: Arrest the sudden cooling when it has reached V. Below V no serious crystallization will form; at or slightly below V no serious stress will exist. Below V your carbon will change from hardening to non-hardening, and your steel, when cooled, will be fine-grained, will be free from stress, will be soft and tough.

Another course is to cool suddenly and completely, and then to reheat, as in tempering common tools of steel. But for large and costly pieces, this may be dangerous and costly; dangerous because the complete sudden cooling may crack the pieces; costly, because the piece has to be heated after the sudden cooling, while by the methods I have described the heat which the metal still contains when its sudden cooling has been interrupted at V suffices for tempering or annealing it.

If, however, the metal has been suddenly and completely cooled, and if we wish to remove the hardness and stress which sudden cooling has set up, *i. e.*, to temper, let us remember that this tempering is but one form of annealing, aiming to remove stress and to enable the carbon to change from the hardening to the non-hardening state. To accomplish these things we need not heat highly. At V it is probable that all severe stress is removed in most cases, and that the carbon changes wholly to the non-hardening state. Needlessly high heating cannot more than accomplish these things, and, if carried materially above W, it will again lead to coarseness of grain.

Up to this point I have assumed that we sought great toughness, softness, and freedom from stress. But moderate stress may strengthen greatly. Witness the initial stresses intentionally introduced in ordnance manufacture. A moderate amount of hardening carbon, while diminishing the toughness, increases the strength greatly. For many purposes, then, we seek moderate stress and moderate hardness. For such purposes the methods which I have sketched may be modified by carrying the sudden cooling to slightly below V.

By varying the rate of cooling and the range of temperature through which cooling occurs, we will vary the resulting stress and the proportion of the carbon which remains in the hardening state, while preserving fineness of grain more or less completely. Clearly a rate and a range of cooling most fitted for one purpose and for steel of given composition may not be the best for other conditions and other steels. To adapt the treatment to the material and to the special needs of the object we are making will be a difficult but not necessarily a very difficult task, once the general principles which govern us are clearly grasped. To arrive at great excellence in these methods of heat-treatment, much closer control of temperature is needed than we have at present. To-day we rely on the eye exclusively. We need not only greater knowledge, but the problem must be studied with the pyrometer, with the microscope, with the testing machine, and by proximate as well as ultimate chemical analysis. This problem I believe to be the one which to-day presses the steel maker and user most closely. May you and I not only live to see, but may we hasten its solution.

## A NEW NICKEL ALLOY.

By J. T. HALL, Sheffield.

THE alloy is formed by the addition of from 2½ to 50 per cent. of nickel to ordinary Bessemer or Siemens steel. The properties which are obtained by this mixture are a close grain, great strength and toughness, and the capability of receiving a brilliant polish; and it is intended for employment in the manufacture of shells, gun barrels, armor plates, etc. The steel may contain carbon, silicon, chromium, tungsten, manganese, or any other of the well known ingredients, but it is preferable to reduce their proportions as much as possible. In carrying out the manufacture, the iron or steel is melted, and the required proportion of commercial nickel is added. The resulting alloy may either be cast into shape, or rolled or forged.

## HYDRAZINE.

IN the course of investigations on the diazo and azo compounds of the fatty series, Th. Curtius and J. Lang* have shown that when the ethyl salt of diazo-acetic acid, $CHN_2CO_2C_2H_5$, is treated with a concentrated aqueous solution of caustic alkali, a salt of triazo-acetic acid, $C_2H_2N_6(COOH)_2$, is formed. This acid is stable in the free condition, and when boiled with mineral acids it gives up its nitrogen in the form of hydrazine, $N_2H_4$. The main reaction involved is that represented in the equation:

$$C_2H_2N_6(COOH)_2+6H_2O=3C_2O_4H_2+3N_2H_4$$

The oxalic acid, which is the other product of the reaction, is, however, more or less completely transformed into carbon dioxide and formic acid—a fact which is expressed in this equation:

$$C_2H_2N_6(COOH)_2+6H_2O=3CO_2+3HCOOH+3N_2H_4$$

Hydrazine is formed also by the following reactions:

1. By reduction of ethyl diazo-acetate by zinc dust and acetic acid, † or by aluminum or zinc filings in alkaline solution; and,

2. By boiling with water the addition products which the ethereal salts of diazo-acetic acid form with the ethereal salts of unsaturated acids.

The decomposition of triazo-acetic acid is, however, by far the best method for preparing hydrazine. The yield is about 90 per cent. of the theoretical.

Th. Curtius and R. Jay ‡ have made hydrazine and its derivatives the subject of an extensive investigation, the results of which are briefly summarized in this note. As regards the quantities with which they worked, an experiment is described in which they treated 245 grms. of triazo-acetic acid in two liters of water with 300 grms. of pure concentrated sulphuric acid. On cooling, pure hydrazine sulphate was deposited in colorless crystals. On evaporating the mother liquor, a second deposit of the sulphate was obtained. From the last mother liquors the remaining hydrazine was extracted by shaking with benzoic aldehyde, with which it forms an insoluble compound of the formula $N_2(CH.C_6H_5)_2$, called benzalazine. From benzalazine the hydrazine is then obtained by treating with sulphuric or hydrochloric acid:

$$(C_6H_5CH)_2N_2+3H_2O+H_2SO_4=2C_6H_5CHO+N_2H_4.H_2SO_4$$

Hydrazine combines with one or two molecules of monobasic acids to form stable salts. Even in acid solution these have extraordinary reducing power, the products of the action being nitrogen and water. When heated alone they decompose at a high temperature, forming ammonium salts, nitrogen, and hydrogen. When a nitrite is added to hydrazine salts, nitrogen is rapidly evolved. Of the salts thus far examined, only the sulphate is difficultly soluble in water. The salts are either insoluble or but slightly soluble in alcohol. Some of them crystallize very well, and most of them appear to be isomorphous with the corresponding ammonium salts. The physical properties of hydzazine itself are as yet unknown. It appears from what has thus far been learned that it is a gas or a liquid boiling at a low temperature.

That its molecular weight is correctly represented by the formula $N_2H_4$ follows from the existence of the two hydrochloric acid salts, $N_2H_4.HCl$ and $N_2H_4.2HCl$, and also from the results obtained in determining the molecular weight of benzalazine by Raoult's method. The compound has a remarkable affinity for water, and forms a hydrate of the composition $N_2H_4+H_2O$. As in settting hydrazine free from its salts it is necessary to use the oxides or hydroxides of the alkali metals or of the metals of the alkaline earths, and as water is necessarily formed in the reaction, thus,

$$N_2H_4(AH)_2+M_2O=N_2H_4+H_2O+2MA,$$

it follows that hydrazine is always obtained in the form of the hydrate. An attempt was made to break up this hydrate by distilling a mixture of hydrazine dichloride and quicklime from a silver vessel, and passing the volatile product through a silver tube filled with pieces of quicklime. No gas was obtained, and only a small quantity of a liquid came over. This proved to be hydrazine hydrate. It was shown further that barium oxide has not the power to decompose hydrazine hydrate into water and hydrazine.

A large quantity of the hydrate has been made by distilling the sulphate with potassium hydroxide from silver vessels, and fractioning the distillate. Details in regard to this remarkable compound will be given in a later article by Curtius and Schulz. Meanwhile the following is all that is said concerning it. It has the composition $N_2H_4+H_2O$, and forms a colorless, inodorous liquid with a high refracting power, which fumes in the air and boils without change at 119°. Pure hydrazine hydrate does not change in closed vessels. At the boiling temperature it attacks glass strongly, and destroys cork and rubber. It has an alkaline taste, and leaves upon the tongue a burning sensation. It is an extremely active poison for lower organisms.

Hydrazine is the strongest reducing agent known. A neutral solution of platinic chloride is reduced to metallic platinum, which separates in beautiful pieces having a silver luster, or in the form of a mirror. In acid solution, on the other hand, platinic chloride is reduced only to platinous chloride. In the same way hydrazine hydrate precipitates all easily reducible metals in the cold. Silver separates in compact lustrous pieces, apparently of crystalline structure. With very dilute solutions most perfect mirrors of great beauty are obtained. From aluminum the hydroxide is precipitated; and chromic hydroxide is precipitated from solutions of chromates. With mercuric chloride there is first formed a yellow colored double salt, from which metallic mercury soon separates. In acid solution ferric chloride is reduced to ferrous chloride, and cupric to cuprous chloride. Dropped upon mercuric oxide or quinone, hydrazine hydrate causes an explosion. The facts mentioned show that this substance is undoubtedly destined to play an extraordinarily important part in analytical chemistry, and extensive investigations are now in progress with reference to its applications in this field.—*I. R., in Amer. Chem. Jour.*

* J. prak. Chem. [2] 38, 521.
† Ibid. [2] 38, 440.
‡ Ibid. [2] 39, 27.

[Continued from SUPPLEMENT, No. 691, page 11043.]

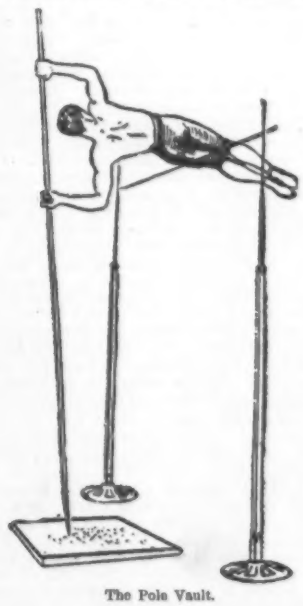
[FROM THE BOSTON HERALD.]

## GYMNASTIC EXERCISES AND APPARATUS.

THE leading gymnasium managers, whose lives and studies are devoted to the cause of physical culture as a basis for all that contributes to happiness and health, hold it as a fundamental principle that the exercise that furnishes the most pleasure and greatest amount of fun will bring about the best general results, provided the local effects of such exercises are taken into consideration. The recreative and pleasurable elements in gymnasium exercises are introduced in various manners, and such elements in gymnastics are always found to add to their interest and make the results of gymnasium work profitable. This element of recreation is brought about in many ways, and by such simple methods that an occasional or constant gymnasium attendant does not realize how or why some of his ordinary dry and apparently uninteresting exercises are relieved of their monotonous elements.

The Hitch and Kick Pan.

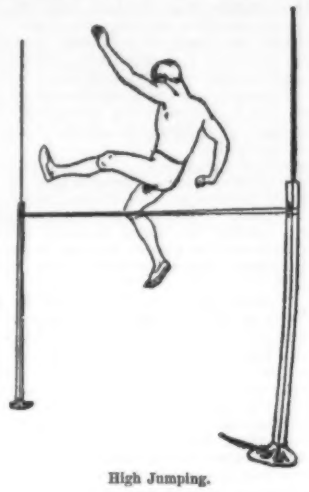
Every good gymnasium instructor devises means to make pleasant the exercise given his clientage, and hours upon hours of study are spent by leading authorities thinking out some simple ways of making the gymnasium agreeable and attractive. The changing of one's conventional street garments for the light and flexible costume of the exercising room, though simple in itself, certainly is out of the ordinary, and is recreative. Such a change is also beneficial to one's health, and acts in conjunction with the exercise and bath which follow. The hanging of mirrors over the gymnasium apparatus, so that the operator can watch the immediate effect of exercise on his form, is recreative, though few stop to realize that fact; and it tends to keep up the interest in the exercise. The hanging of a portiere here, the changing of apparatus there, and varying from the ordinary lines of gymnastics now and



The Pole Vault.

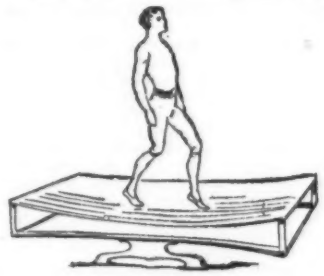
again—all combine to add zest to the work given a gymnasium attendant by an instructor. For this reason the most popular gymnasiums of the day are constantly changing in their appointments, and undergoing a state of transition, both in methods and mechanism. For this reason, too, novelties in the way of gymnastics are introduced, and apparatus that may or may not be of value as a special developer, and only of trivial value as a general developer, is often put to good use in the hall of health, because it furnishes the means for unbounded sport, recreation, and fun.

The kicking disk, or pan, which is the name of a common ordinary pan of tin or plate of cardboard, about twelve inches in diameter, round in shape, cover-



High Jumping.

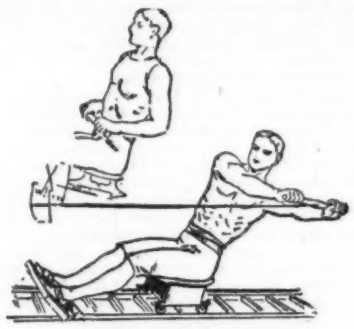
ed with leather, and suspended from the ceiling by a string, is a piece of apparatus which might properly be classed in the line of special recreative developers. This disk can be raised or lowered to any elevation to suit the height or agility of the man seeking exercise from its use. As nearly every one knows, the disk is confined in its use outside as well as inside the gymnasium to men who want to learn to kick or jump and kick or hop high. Men who use the kicking pan constantly, rarely, if ever, think of the development of the muscular system that its use brings about. If they only stopped to think, or asked questions of competent instructors about the effect of such recreative or pleasurable fun or exercise, they would learn that they were developing some parts of the body with violent movements very rapidly, while other portions of the body were being neglected, and they were thus leading on to unbalanced development, the effect of which they should counteract by the use of other appurtenances. The muscles which a man develops more especially than any other in the constant use of this disk by kicking at it while it is suspended at an easy height are those of the entire lower limbs, the external and internal attachments to the hips and spine, and those related to the anterior part of the ribs and chest. The muscles



The Springboard Bed.

around the shoulders, that raise the arms when they are thrown up to get the "lift," are slightly developed, as are also several smaller muscles of the upper body. Unless some contradicting exercise is taken to leave the muscles around the abdomen in a normal condition, after this exercise is taken, a stooping position and immobility of the chest will be the result. If a strong man desires to confine the action of the kicking exercises on this machine to the anterior and lower part of the body, he kicks at the pan with both feet raised at once, while facing the pan. To counteract the effect of this movement on the same piece of apparatus he should stand back to the pan, and kick back and up, striking the pan with the ball of his foot or toes, at the same time throwing his hands high over his head, and together, thus curving the body in a half circle. This movement develops the muscles in the posterior part of the body, and tends to give an erect carriage. The latter movement is approved of because it stretches the muscles contracted in the front part of the body by forward kicking exercises, and because it leaves the body in a correct, healthy, upright position by developing the heavy groups of muscles in the back that are oftentimes neglected.

There are very few elements of danger in kicking at the disk if one is careful to keep control of the body and limbs at all times, and avoids jumping carelessly, in which latter case one is liable to strain the ligaments and attachments of the groin. A piece of apparatus that may be classed in the same category as the kicking disk, though the elements of danger prevent its very general use, is the pole vaulting apparatus. This consists of a long pole similar to that used by river drivers in logging, with a pointed iron end, a small square platform of wood, and two jumping standards with cross stick that can be raised to the height of about twelve feet. The man desiring to vault, with the assistance of the pole, over the stick at any extreme height, grasps the vaulting pole with one hand at just about the height of the cross stick, with the other hand higher up. Then he gets as far back from the object point in jumping as he desires, takes a run till he gets within a few feet of the square platform in front of the vaulting standards with the object stick set on them, thrusts the sharp end of his pole into the wooden platform, and over he goes, assisted by the momentum of the run and the strength of the arms and the body he applies by the purchase he gets by pushing down on the pole. When he is in midair and over the object stick, he releases his hold on the pole by pushing it back, throws his arms high over his head, and sails gracefully down to the mattress on the other side. The exercise tends to cultivate self-control of the body,



The Rowing Weights.

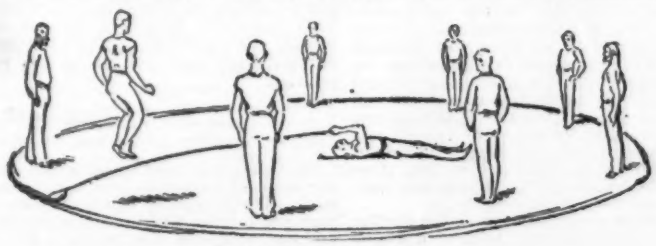
and acts as a general developer of the muscular system. The run which one gets in the first part of the vaulting movement develops the legs, the pushing down on the pole and the throwing of the body over the object stick develops the muscles of the upper part of the body, varying in the style of vaulting, and the extending of the body and the throwing of the hands high up over the head in the last movement of the finely finished vault leaves flexible the muscles developed in the other movements.

The same jumping standard and cross stick used in pole vaulting are brought into requisition in standing or running high jumps, and in a measure the same muscles of the body, excepting those of the arms, are developed. High jumping is a pleasing pastime for constant gymnasium attendants to practice for the purpose of relieving the monotony, if they find it such, of special or tiresome gymnasium work; that is, if they desire exercise more particularly of the lower limbs

The Hydraulic Rowing Machine.

than of the upper section of the body. There is no set rule for a high jumper to follow, and for that reason many styles of jumping are seen. The effect of high jumping, whether what is known as straight or side jumping, is to develop almost identically the same groups of muscles and the body. If jumping is done in a proper and scientific manner, and the end of the jump is perfect, the effect will be to help build up the system in many ways, and corrective exercises will not be found necessary. Men who make a practice of jumping seldom jump in a proper manner, and for that reason most specialists in that line carry themselves in a stooping posture, and are flat chested. They are by no means models for the athletic world. A corrective exercise for their style of work can be had by special exercises on the giant pulleys, sternum elevator, or back of neck and small of back machines.

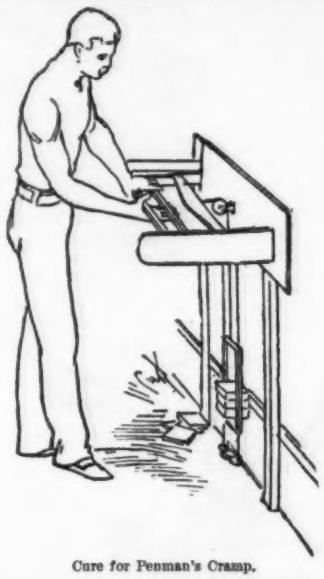
The springboard bed, or bed of springboards, a good cut of which is shown herewith, is one of the simple pieces of gymnasium apparatus that is of no especial value as a special or general developer, but which adorns the floor of the gymnasium because it can be used with safety, and its use varies the monotony of exercising with other apparatus. There is everything simple and of an ordinary character in the use of the springboard, and the fun derived from its use is unbounded, while the exercise is sure to assist, if taken with moderation. Exercise on the springboard consists principally in going through the movements of running and jumping on it, and getting the same muscles developed in so doing without getting off the board as would be obtained in running or jumping in the



The Skip Rope Exercise.

open field. The effort on the springboard in so doing is not nearly so great as it is in ordinary running or jumping exercises, and for that reason the weak man can use the board for the elements of fun there are in its exercises and, at the same time, develop the lower limbs and, if he cares to by other movements, parts of the upper body, just the same as the strong man develops the muscles of his lower limbs in open field running or jumping competitions.

Exercise on the springboard is an aid to good digestion, as much, in fact, as either running or walking indoors, for the jolt given the upper frame at each landing of the feet on the bed of the board gives nearly the same effect on the digestive organs as does horseback riding. The sensation of jumping on the board is very



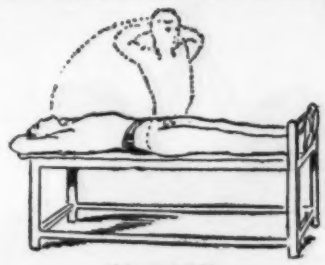
Cure for Penman's Cramp.

pleasant, and for that reason, wherever a springboard is found in a sanitary gymnasium, its use is almost constant, if the gymnasium membership is large and active. For the purpose of leg development, agility, and training of the eye, a so-called skip rope, or ordinary rope, with bag of shot attached to one or both ends, is used. This can be put to good use in a class. A man stands in the center of a ring, with from half a dozen to a dozen men on the outside. The one in the center swings the bag of shot around so that all on the outside will be obliged to jump over it and watch its course around the circle, jumping over it as it comes their way. The result of this exercise will be to develop the parts mentioned above. This skip rope circle exercise furnishes an immeasurable amount of fun, and keeps life in many gymnasiums among men who are too lazy to work but believe in play, which unconsciously and incidentally develops.

Of the special developing apparatus which is noticeable in gymnasiums, and which the *Herald* has not as yet noted, the rowing weights and hydraulic rowing machine are useful and entertaining. The rowing weights are nothing more than high pulley weights, with a stick attachment at the end of the rope which the operator catches hold of, while sitting on a box made after the style of the sliding seat. If the operator desires to develop his loins, he draws the pulley attachment to his right or left side with stiff arms, getting resistance from the weights in the box. If he desires to strengthen his back, he holds his arm stiff and draws the line over his head. If he desires to strengthen any other part of his body, he can do it in the same way that he does with the ordinary pulley weights; or, if he desires to get the rowing movement, the machine can be so used without a change.

Intercostal Machine.

These machines are almost invaluable in a gymnasium, as they are good for general developing exercises of all kinds, and are especially valuable to fat men. The hydraulic rowing machines, which are better illustrated than they can be described, are for the purpose of giving the operator as near as possible the same movements and resistance as he would get if handling a single oar in a crew or a pair of oars in a single scull. Long before the rowing tanks were introduced, these hydraulic machines served many a crew a good purpose, and gave them realistic rowing exercise and muscular development. There is no secret in their use, and all that can be said of them in that respect is that the oar handle of the machine is worked in almost exactly the same way as the oar in a boat. A sliding seat for the operator to sit upon is generally provided with the machine, and serves the same purpose as the sliding seat in a boat. This machine should not be used by flat-chested men without directions, which say that in pulling the oar handle back they should not bring their bodies beyond a vertical sitting posture. They should pull the oar down close to the hips, keeping the elbows close to the sides while throwing the chest up and forward, and holding the head erect by stretching the chords of the front part of the neck and developing the back part of the neck. This



Abdominal Table.

finish develops the back muscular chest, and helps to give an extremely erect carriage and full front chest. The operator should avoid leaning back and pulling the shoulders up while exercising on this machine, as such exercise overdevelops the straight muscles of the abdomen and the muscles at the top and back part of the shoulder blades. For the purpose of curing "penman's cramp," as well as for developing and strengthening the muscles of the forearm or sinews of one's hand, a novel and beneficial machine is in use in many gymnasiums.

This machine looks like a hat rack or pillow sham holder when it is not in use, though it is set only as high from the floor as one's waist. The working part of the machine is a rack within a rack, about two feet wide by two feet long. The inside rack slides backward and forward, and is made of a frail framework, held in place by three or four small rungs run horizontally across it at distances of about six inches apart. The operator stands in front of this framework, rests his wrist or ball of his hand on the outside frame of the stationary rack, and catches the outside rung of the sliding frame or rack with the tips of his fingers and pulls it toward him. To the rear frame of the sliding rack is attached a rope, which is run through a pulley block to pulley weights. As the framework is drawn forward the weights are pulled up and form just as strong resistance to the strength of a man's finger as he desires to have. The operator must, of course, shut his hand up more and more as the sliding frame moves toward him, and when he has drawn it up close to the stationary frame he may let the sliding frame slowly recede to its original position, where it is drawn by the pulley weights in their descent. Whether the palms of the hands are faced upward or downward in exercising the fingers or forearm on this machine, the same muscles are developed. Excessive use of this machine tends to give the fingers an unnatural curve, because of the artificial tension brought about by the over-development of the flexors of the forearm, or the muscles that shut the hand up.

In gymnasium drills, beginning with work for the extremities, the bad effect, if any, of this machine is offset by the easy closing and then hard opening of the hands and extension of the fingers, thus developing the muscles giving an artistic roundness to the forearm.

The abdominal table which is shown in the accompanying illustration serves the same purposes as the abdominal mat. It is more especially for the purpose of decreasing the avoirdupois of the fat man and working off the excess in size of a ponderous stomach. The exercise for accomplishing this purpose is a perfectly natural one, and consists only in lying down at full stretch on the table, putting the feet through the opening in the end of the table, and coming up to a sitting posture with the hands clasped behind the head. This movement, with other light, quick movements, tenses up the muscles of the abdomen, fries out the fat and draws in the walls of the waist, thus making many a fat man lean and happy.

Fence Vaulting Apparatus.

The exercise of fence vaulting, as shown, is a first-class general developer, which is seldom practiced to excess. Fence vaulting is more of a sport than an exercise, and it has its ill effects as well as its interesting and beneficial features. It is a type of those heavy exercises that over-develop the muscular system, yet it is not as liable to be of injury as are most of such exercises.

The fence vault in a gymnasium is done in very much the same way as a vault over a fence in the field, and it tends more particularly to develop the muscles around the shoulders and upper part of the body than anywhere else. Constant training for competition in this branch of athletic sport tends to slowly but surely over-develop and harden the entire muscular system, consequently putting a great strain upon the heart, which must necessarily increase in size to supply the abnormal demand brought upon it. After over-developing the muscular system, together with the heart, if one fails to continue to keep up the vigorous muscular tone of his system, his heart, being a part of his muscular system, becomes flabby and sometimes it becomes dilated and weak. A weak heart, whether from lack of development or from the above cause, never yet has won honors or fair ladies. The intercostal machine has the effect of offsetting the local ill effects on the forms of those who practice fence vaulting, by enlarging the interior chest capacity and flexibility of the chest wall. It is used for enlarging the chest diameters, and is operated in the manner illustrated.

Modern methods of exercise in a gymnasium make the body a serviceable contributor or servant of the whole man, supplementing the church, the school, and the home in the development of the youth.

## A NEW POLARIMETER.

THIS was lately described before the Physical Society, London, by Professor Silvanus P. Thompson.

In the earliest apparatus, dating from the time of Biot, the polarizer usually consisted of a bundle of glass plates, and the analyzer of a double image or Nicol prism, which was rotated until the maximum extinction was obtained. With this apparatus it was difficult to obtain accurate results, because the angle of rotation to produce complete extinction was not the same for all colors.

In 1845 Soleil introduced the bi-quartz plate, in using which the eye had merely to make a comparison between the tints of two halves of the visual field. Pohl, in 1856, effected the same object by means of a thin plate of mica covering part of the visual field. In 1874 Laurent improved upon this by covering half the polarized field with a half wave plate of quartz, an arrangement known as the "saccharimètre à pénombres," or half-shadow polarizer. In 1860 Jellett introduced the triple image prism, in which, on opposite sides of an ordinary image, two extraordinary images are obtained, having their planes of polarization inclined at a small angle. When, therefore, one of these images is at maximum extinction, the other will not be quite extinguished, and as a small angular displacement will greatly affect the relative brightness of the two images, they can be very accurately adjusted to equality. In 1873 Cornu suggested a modification of this method, consisting of a Nicol prism divided longitudinally in a plane perpendicular to the balsam film, and having a small wedge cut away, and then reunited with the balsam, giving, in the two halves of the visible field light, polarized in planes inclined at a small angle.

In 1878, Schmidt and Haensch improved this by cutting out the wedge from one-half of the Nicol prism only, and then reuniting the parts. In 1882, Lippich suggested for the same purpose covering half the polarizing field with a smaller polarizing prism rotated through a small angle, which, while attaining the same result, allowed of adjustment of the angle. Pickering suggested the use of a double image prism, arranged to give two contiguous but oppositely polarized images of a rectangular aperture placed beyond it, which would appear to be equally illuminated when the analyzer was at an angle of 45°. In 1886, the author described some polarizing prisms constructed for him by Mr. Ahrens, on the principle of finding a pair of characteristic planes within the crystal of Iceland spar at right angles with the terminal faces, which were principal planes of section, passing through the line of intersection made by the terminal faces with the natural faces of cleavage. These prisms, owing to the fact that the crystallographic axis is inclined at almost exactly 45° to the rectangular edges, have the peculiarity that if reversed, when used either as polarizer or analyzer, a dark field is changed into a bright one, or *vice versa*. In 1887, the author described some twin prisms found by taking two prisms, as last described, of rectangular cross section in the ratio of 2: 1. These were placed side by side, so that the light passed through them, the visible juxtaposed fields of vision forming the two halves of a square. Suppose one prism to be reversed end for end, then the field of vision would still be a square divided into two halves, which, however, would be oppositely polarized. Such a prism could therefore be used like the Pickering prism, or half shadow combinations. In another twin prism the same method of construction was employed, except that after the prisms had been cut, a small wedge of about 2° 30′ was ground away from the side of one of them, after which they were juxtaposed, giving this amount of angular displacement between the two halves of their joint visual field. In both cases the prisms were ground together and joined by balsam, so that the observer would only see a fine line of junction down the center of the visual field. These prisms possess the following advantages: There is much less loss of light by reflection at oblique surfaces than in those of Righi. There is no difference in the angular displacement for light of different wave lengths, as is inevitable when quartz, mica, or sugar is used to produce a rotation in one half of the field. They are preferable to Jellett's prisms, because the fields to be compared are immediately juxtaposed. The author desired to adapt the half field method to reflecting polarimeters, and he succeeded in doing this in an instrument which he exhibited at the meeting. In this instrument a square Nicol prism was used as analyzer, while the polarizer consisted of two small plates of black glass inclined to each other at an angle of about 2°, and placed at the proper polarizing angle. This instrument gave very good results with solutions which did not absorb much light. For dark colored solutions the author preferred, however, to use a twin prism as polarizer.

When mica plates are used, instead of covering half the field with a half wave plate, he covers one end entirely with a quarter wave plate, and the other with two quarter wave plates inclined at an angle of 45° on each side, and, therefore, perpendicular to each other, which gives the same thickness of mica over the whole field.

The author then exhibited some crystals of salicene

and benzoic acid together with a transverse section of a stalactite. In each case, when viewed by polarized light, a black cross was seen, which remained stationary when the field was rotated. The author suggested that this was due to a radiating structure in the crystal, in confirmation of which he showed that the same results could be obtained from an artificial crystal built up of a number of sectors.

## CAPTURE OF A DEVIL FISH.

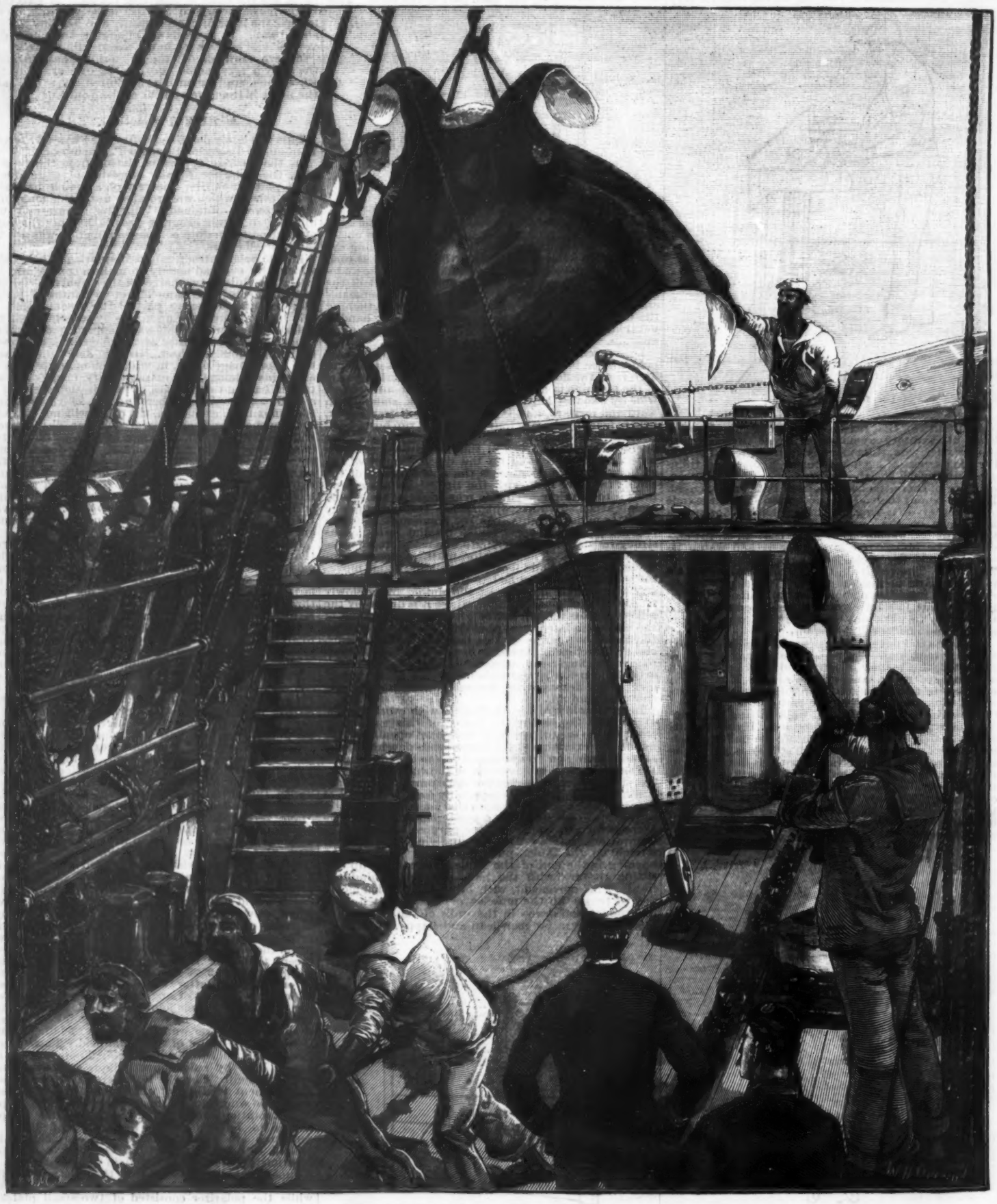
We are indebted to the Rev. W. C. Bourchier, R.N., chaplain to H.M.S. Comus, in the West Indies, for the sketch of this incident, accompanied by the following account of it:

"As her Majesty's ship Comus lay at anchor in English Harbor, Antigua, the little barrel-like buoy that marks the place of the anchor, to which it is fastened by a four inch rope, was observed to plunge about and splash, diving under the water and disappearing. Reports of this unseemly behavior of our buoy were conveyed to the officers, who treated them with the cautious suspicion that such an unlikely story seemed to deserve. By one o'clock in the afternoon, when the buoy had danced for an hour and a half, and seemed to require some looking after, a boat was dispatched to its assistance. The cause of the disturbance was then manifest. A huge devil fish had got foul of the buoy rope, and there he was, struggling away, about six feet below the surface of the water, with two good turns of the rope around one of his mouth fins, as I may call them for want of a better name.

"He was secured with a sharp hook by a gallant midshipman, and was then harpooned; the rope in which he was entangled was cut, and he was slowly towed alongside and was hoisted inboard.

"When he was laid on the deck, we had an ample opportunity of admiring his vast proportions. He was not 'a thing of beauty,' but an awe-inspiring monster of the deep. There lay the great fish, like a giant black bat, with his huge wings extended on the deck, measuring across, from tip to tip, 16 ft. 4 in. The other dimension were: breadth of mouth (horizontally) 3 ft.; length from head to end of tail, 12 ft. 8 in.; length of tail alone, 5 ft. But it was a puzzle, at first, to find out where his mouth was placed.

"'I have it, sir,' cried a bluejacket in great glee; 'and, what is more, he has a fish in it—his dinner is there!' As he spoke he opened a pair of great black lips, rather to one side of the fish, I thought; and below these lips was a white cavity, large enough to contain one's head. And there was a fish sure enough, inside it, but this little fish was alive; he bounced out, a fish the size of a small herring, and skipped furiously about the deck between our feet. There were more wonders presently, when another bluejacket found another mouth, with another fish in it, alive and well, and this fish, too, came out and skipped on deck between our legs. Then it dawned upon us that these small fishes could never have been eaten by the big devil fish; and further examination showed that each of them had a flat plate on the back of its head; it looked as if they had held on to something by this 'sucker,' and it proved that so they do. We put them in a bucket of water, and they hung on to the side of it with the back of their heads so vigorously that the hardest pull could not shift their position, much less dislodge them; though, when the bucket was emptied, they came off its side at a touch. The small fishes had clung to the devil fish as his parasites; not feeding on him, for they had left no mark behind, but using him for their traveling habitation. The



CAPTURE OF A DEVIL FISH.

cavities in which they lodged were his nostrils. Meanwhile, we discovered the real mouth of the devil fish, three feet across, lying between these cavities. This enormous mouth is quite toothless; the devil fish sucks down his food as one would an oyster. What is his food? I cannot tell; for after I had finished sketching him, and before I had well begun dissecting him, orders were given to heave him overboard, as he was making the deck filthy with the streams of blood that continued to flow from his dead body.

"Stories have been told of the devil fish taking a luckless swimmer between his great fins, folding him in a deadly embrace, and sinking with him to the depths below; and this may be true enough; but the Manta Diabolus, or Manta Birostris, as he is scientifically called, is said to feed only on seaweed. At the same time, he is troublesome and even dangerous, fond of meddling with the mooring of fishermen's boats, as he did with our moorings, and setting them adrift, and when pursued—a favorite pastime, when they were more plentiful, at Port Royal—turning upon the boats, and, if not quickly dispatched, capsizing them. I have often seen these fish leap out of the water—an amazing sight—on the coast of Venezuela, where they are common, and grow to the size of 20 ft. broad.

"In the scene represented by my sketch, when the order to throw the monster overboard has been given, it is promptly obeyed. Eighty men strain at the ropes; the fish, whose weight may be a ton, slowly rises, and swings round, presenting a very odd and even astonishing spectacle. Over the sea he hangs for a moment; the word is given, 'Let go;' then down he falls with a crash, disappears in a cloud of foam, and sinks to the bottom of English Harbor."—*Illustrated London News.*

[THE NATION.]

## IRRIGATION IN COLORADO.

IN the United States, irrigation is employed extensively in Colorado, Utah, and California. Colorado has by far the greatest irrigable area, and there the laws respecting the use of water for agriculture are the most perfect. Nature seems to have ordained that this State shall lead in irrigation. Within its borders are congregated the highest ranges and peaks of the Rocky Mountains. It is the veritable dome of the continent. On the countless square miles of its lofty summits fall the heaviest mantles of snow, the sources of an unfailing water supply. All the great rivers west of the Missouri, except the Columbia, commence their courses in this State. The Platte, the Arkansas, the Rio Grande, and the Colorado rise nearly together in central Colorado, and in summer are large, swollen rivers before they leave its confines. No Western State or Territory, therefore, is nearly so abundantly supplied with water and streams as Colorado. This advantage, together with its favorable location with respect to immigration, and its vast extent of most fertile farming land, assures to it the foremost rank in agriculture among the mountain States.

The canal system of Colorado at this time embraces 5,000 linear miles of large and small ditches. It represents investments of private capital amounting to $12,000,000, and furnishes water for two and a half millions of acres. So attractive are canal enterprises to those familiar with them, that many miles of canals are now being constructed, notwithstanding the fact that there are at this time fully one million acres of fine, unoccupied, and unimproved land situated in the irrigated territory. The young State needs people rather than reservoirs and more canals.

The water of every natural stream is declared by the constitution of Colorado the property of the public, and is dedicated to the people's use. There are no riparian rights. The canals are taken out of the rivers and creeks, and at present furnish water only for valley lands. The fertile plain ranges and smooth mesa or table lands lie above the level of the streams, and must eventually be supplied with water by great and costly systems of reservoirs. When all the water of a stream is claimed and appropriated by ditches, it becomes a sort of contention among its users, and the law is active in determining and enforcing the rights of the respective canal companies. The law is based on the principle that the right to water is acquired by priority of utilization, that is to say, the courts hold that water should not be taken away from those who first have utilized it in good faith. If, for instance, a canal has used the full capacity of a stream, it is forever entitled to all the waters of that stream. The volume of a river from which several canals are conducted having been estimated in cubic feet per second* of time by the State engineer, each ditch company appears before the District Court, which has jurisdiction subject to appeal to the Supreme Court, and shows when it was constructed, what its capacity is, and how much water it has used, or can use, for actual tillage. The court thereupon decrees to each company the number of cubic feet of water per second it is entitled to draw each season from the stream, and its rank of priority, *i. e.*, its order of precedence with respect to other canals supplied from the same stream.

These decrees are, of course, enforced. The State engineer has general supervision of all matters pertaining to irrigation, and he is required by law to see that water is distributed in accordance with the court's injunctions. The State is divided into water districts, and for each district the governor appoints a water commissioner, whose term of office is two years. It is his duty to divide the water in the streams of his district among the several canals, according to their rights as determined by the court; and, if need be, he may summon the sheriff to assist him in the discharge of his duties. The water commissioners are under the direction of the superintendents of irrigation, who have charge of water divisions, each division embracing several water districts. The especial duty of the superintendents is to see that the laws are properly executed, and that the judicial decrees are enforced by the commissioners. The superintendents are under the general supervision of the State engineer, and anybody has a right to appeal to him from a superintendent. The commissioners must report fully to the superintendents as often as the latter desire, respecting the supply of and demand for water in their respective districts, and all other matters deemed worthy of attention.

So much for the relation of the State to the canals. What are the farmers' relations to them? Water is disposed of to consumers in two ways—by rental and by absolute sale of the right to it. A company rarely attempts to dispose of water under both plans, for that has not been found practicable. A corporation seeking a permanent investment may construct a canal for the purpose of renting water to farmers at an annual rental "per inch."* Water rents in Colorado are from $1.50 to $2.50 an acre (or an "inch") per annum. If a farmer regards the rental exorbitant, he may have the matter brought up before the county commissioners, who, after hearing evidence on the part of the consumer and the company, can fix the sum. Their decision is final, so that practically the people control the rate. The principle which inspires the law to adopt this procedure is that the canal companies do not own the water, but are public carriers. If a farmer has once used water on his land, he can always compel the company to furnish it to him upon tendering each year the rental price established by the commissioners, the theory being that water, once applied to a tract of land, is a fixed appurtenance as long as the rental is paid. It cannot be transferred by the company or the farmer to other land without the consent of both parties.

But the usual and most popular plan of disposing of water is to sell a "perpetual right" to its use. When the constructing company on this plan has sold all of its water, the canal is owned and operated by the farmers as a stock company, shares of stock representing "inches" of water. The corporation is then a mutual company, escaping the hindrances of law; and the consumer owns the right to his water and pays only the annual charge for "maintenance and operation"—generally ten cents per acre. "Perpetual rights" on this plan are worth from $5 to $25 per acre. While the parent corporation exists, the purchaser obtains a deed or contract for his "perpetual water right"—a temporary evidence of the right to use water. A "perpetual water right," or simply a "water right," is a right, good for all time, to sufficient water to irrigate 80 acres. When the farmers reorganize the company on a final basis, "water right" contracts or deeds are superseded by shares of stock.

How the consumer farms under the irrigation system, and what are some of his advantages, next deserve notice. The farmer must conduct the water to his land from the head gate, or opening, through which he takes his supply. The head gate is always under the control of the superintendent of the canal, who divides the volume among the users. Each man's water flows over a weir—a device for measuring exactly how much the consumer receives. A lateral, or small ditch, is built from the main canal by the farmers of a neighborhood, and from it each takes his share of the supply. The user contrives to conduct his water along the highest side of his farm in a smaller lateral, whence the stream is distributed over the fields by flooding, or conveyed in small channels between the rows of crops. Crops are usually supplied with water three times, from the middle of May until about the first of August. A skillful man can irrigate from 80 to 120 acres of grain during a season, and can "go over" 80 acres in 8 or 10 days. In the fall another irrigation usually takes place, so that the ground may be in condition the following spring to germinate the seed. Very rarely is fall grain sown in Colorado.

Frustrated by neither drought nor flood, the husbandman is able to mature his crops to perfection, to accelerate or retard their ripening, and to bring harvest to suit his convenience. By applying water, he can keep half of his field green while he harvests the other half. The growth of grain is almost marvelous. In parts of the State, solid fields of oats and wheat five feet tall, with heads in proportion, are common. The grain itself is perfect in quality and usually overweights. But alfalfa (or lucerne) and leguminous plants yield the most astonishing results. Alfalfa is the most beautiful, wonderful, and profitable crop raised in the Rocky Mountain region. A field of it, with its sweet-scented, purple blossoms, is a perfect garden of beauty and perfume. It is a kind of clover, and highly nutritious. It grows about two feet high, and, being perennial, its roots reach down usually five feet deep. Alfalfa is first harvested in June, then water is applied, and in four weeks it is cut again; the water is reapplied, and it is ready for another harvest a month later. Each cutting of a good crop will yield two tons. It is worth in Colorado from seven dollars to ten dollars per ton. It will be seen that irrigation is simply an insurance—it assures a certainty of return for the year's work.

In passing from the subject of irrigation in Colorado, attention should be called to the surprising effect of the canals on the volume of a stream. It would seem natural that, if the full capacity of a river were directed into a channel, there would be no supply for ditches lower down the stream. With this in mind, the people of western Kansas and Nebraska, realizing the necessity of irrigation, are inclined to complain because all of the water in the eastern flowing streams of Colorado is appropriated before reaching their borders. However, both experiment and theory show that their fears are groundless. The State engineer of Colorado gives the results of his investigation of this subject in his report for 1885–86, before there was any expectation of interstate contention, and when the people of those parts of the plains more remote from the mountains had no thought of the necessity of irrigation for their region. He made the experiment in the Cache la Poudre, a stream of northern Colorado, and says:

"Starting with a flow of 127,609 cu. ft. per second in the canon, before any water is drawn into canals, the volume at the lower point, after supplying fifteen canals, had increased to 214,508 ft. per second, showing an addition of more than two-thirds of the original amount, to supply canals farther down the valley."

The reason for this is that all the water withdrawn from the river for irrigation gradually seeps back into it, making a steady and reliable current. But for this fact the water would rush down the sandy beds of the rivers in torrential streams, disappear quickly, and be of slight avail for irrigators' purposes.

That irrigation is destined to be practiced widely in the United States admits of no doubt. Without it the western half of our country would not be susceptible of cultivation. All the valleys and great parks and passes of the West—whether at an elevation of 500 or 5,000 ft., whether in the Rocky Mountains, the Sierra Nevadas, or the Coast Range—demand irrigation. The same may be said of the vast arid plains—the "bad lands" of America—which lie between the 22d and 27th meridians. Although their soil is almost as rich as that of the valley of the Ganges, they are without water a desert, and with water marvelously productive. They will some time be covered with extensive and costly systems of reservoirs, stretching eastward from the mountain lakes. Nor is it venturesome to predict that irrigation will some time be quite extensively employed in considerable portions at least of the Eastern, Middle, and Southern States. There are, too, grounds for this prediction. The sure and sufficient supply of water for his crops is the greatest desideratum for the farmer. Irrigation not only provides this supply, but it fertilizes the land. The silt-bearing mountain water spreads rich soil-food over the fields, and renews and reinvigorates them each season. Although the expenses of constructing irrigating canals in the States east of the Mississippi would be great, the enormous sums now expended in fertilizing stuffs, which would not then be needed, might, perhaps, pay the whole cost. If, for instance, the farmers of the Genesee Valley in New York State should distribute over their farms the never-failing waters of their neighboring lakes with the vast amount they pay annually for guanos, their outlay per annum might be no greater than at present and their income would be greatly increased. Guanos add nothing to the permanent melioration of their farms, but the irrigating canals would be a fixed improvement, and making possible the increased revenues arising from the additional quantity and the improved quality of the grain produced, and produced without failure, would add to the value of their farms many fold.—*S. O. Henry.*

* A cubic foot per second is becoming the module in Colorado, and is that volume of water which will flow, during the irrigating season, through an orifice one foot square. It is sufficient to irrigate about 54 acres.

* An "inch" of water means the "statutory inch," *i. e.*, that volume of water which will flow in a second of time through an inch square orifice, under a 5 in. pressure. An "inch" of water is generally considered, in Colorado, sufficient to irrigate one acre; but it is an inaccurate term, and is fast falling into disuse.

## THE EXHIBITION OF THE NEW ENGLAND METEOROLOGICAL SOCIETY.

THE exhibition was opened in the Physical Laboratory of the Massachusetts Institute of Technology, January 15, and was continued seven days.

The Blue Hill Meteorological Observatory displayed instruments used in its regular and experimental work. In the latter class were the registering aneroid barometer, wind-vane, and thermometers used by Professor Upton and Mr. Rotch during the late total solar eclipse in California, besides the registering actinometer put in action probably for the first time in a total solar eclipse.

This instrument, which was made by Richard Brothers of Paris, has a bright and a black globe, in each of which is a thermometer whose indications are registered on a drum, an ingenious device correcting the influence of changes of temperature upon the transmitting medium of the solar thermometers.

There were the Watkin and Hottinger aneroid barometers, the first being intended for mountain use without thereby sacrificing an open scale. To accomplish this the needle travels three times round the dial in its passage from 23 in. to 31 in., and an index, actuated from the axis of the needle, shows which of the concentric circles should be read. In the Hottinger instrument the expansion and contraction of the vacuum box is measured by a micrometer and vernier to the thousandth of an inch. This instrument is the property of the United States Signal Office.

Both the Hilger and Browning forms of rain-band spectroscopes were represented. They are direct vision instruments, and can be carried in the pocket. In the Browning, a scale is reflected on to the spectrum so that the position and width of the aqueous vapor lines can more accurately be measured. Three novel forms of minimum thermometers were shown. One was the hollow bulb thermometer of Hicks, with its bulb, consisting of a hollow glass cylinder about which a second cylinder is blown and united at the open ends so as to leave a thin space between them, filled with alcohol. The stem of the thermometer is connected to a middle point in the outer cylinder.

In the bulb there is a large surface, both external and internal, for the air to come in contact with, and the volume is small, making the instrument extremely sensitive. Another form of minimum thermometer was the *thermometre a marteau* made by Baudin. This is also an alcohol minimum, but can be placed vertical, unlike any other, and its index is not subject to displacement by wind. A spring attached to the index keeps it in a fixed position, but is not strong enough to prevent the film of alcohol from drawing the index downward when the temperature falls. The thermometer is set by turning it bulb upward, when an enamel rod in the bulb descends the bore, and acting as a hammer, forces the index to the end of the column. The third form was the Casella mercurial minimum, belonging to the physical department of the Institute of Technology. A chamber is blown in the side of the thermometer tube, into which the mercury passes as it expands, but not as it contracts, so that the column is left at the lowest point reached.

A simple portable anemometer is the one made by Hicks for the London Meteorological Office. In it the Robinson cups are geared to a dial, but can be disconnected by inverting a sand glass. To determine the velocity of the wind the cups are allowed to acquire the normal velocity before the sand glass is turned over and the registration commenced. At the expiration of two minutes, when the sand has ceased to flow, the glass is reversed and the wind's velocity in miles per hour read off at leisure from the dial. This instrument costs in London $25, and if it could be manufactured cheaply in this country, it would be a valuable adjunct to the equipment of the stations of our State Weather Services. The above instruments, except those specified, were the property of the Blue Hill Observatory.

Among the new apparatus was the recording rain and snow gauge devised by S. P. Fergusson and described in the November *Journal*, and the seismograph made from designs of Professor Ewing, of Dundee, Scotland. In the last named a heavy disk is suspended by three wires, and below it is a vertical weighted rod

in unstable equilibrium. A rod fulcrumed above the disk carries a lever with a pen which inscribes upon a smoked glass plate the direction and intensity of the horizontal components of the earthquake shock. The English instrument cost $75, but it is manufactured in San Francisco for $15. The Harvard College Observatory showed a seismoscope in which the time of the earthquake is obtained by having a pendulum break an electric current and start or stop a clock. Some tracings obtained by a pendulum seismograph of Prof. Ewing in Tokio, Japan, were loaned by Prof. Rockwood.

A form of the Jordan sunshine recorder, modified by Prof. Pickering, was shown by the Harvard College Observatory. It is often difficult to find a position with exposure to both morning and afternoon sun. Accordingly the apparatus is made in two parts—each being the half of a cylinder with its axis parallel to the earth's axis. These half cylinders contain blue print paper, which is acted upon by the sun shining through holes in the flat sides of the cylinders. These holes are moved down a notch each day, so that one sheet of paper lasts a week. One of the cylinders gives a record of the morning sun, the other of the afternoon sun, and the cylinders may be placed on opposite sides of a house, if necessary. Another ingenious instrument devised by Prof. Pickering is the pole star recorder. In this, a telescope and camera are combined so that the trail of the pole star, as it describes a circle in the heavens, is photographed on the sensitized plate, if the sky be clear. Passing clouds cause the trail to be broken. An alarm clock closes the shutter of the camera at dawn, and can be made also to open it after dark. From these records the amount of cloudiness is obtained at night as it is obtained in the daytime from the sunshine recorder. This instrument has been in operation at the Harvard College Observatory for the past year, and one has recently been set up at the Blue Hill Observatory.

The aspiration psychrometer, invented by Dr. Assmann, of Berlin, for obtaining the temperature and humidity of the air under all circumstances, was shown by Mr. Rotch. The wet and dry bulbs of the thermometers are surrounded by a polished metal casing through which air is drawn by bellows at a uniform rate. For use in rain there is a second case to inclose the first. The Piche evaporimeter, a simple contrivance for measuring evaporation, has lately been supplied to the signal service stations, and the amount of evaporation in different parts of the United States approximately determined. It consists of an inverted graduated test tube filled with water, its mouth closed by a disk of filter paper held by a spring. The Fineman nephoscope, or cloud mirror, was recommended by the International Meteorological Committee. It has a black reflecting surface with means for orienting it and sighting the cloud image by which the direction of motion and the relative velocity of clouds can be determined.

Prof. Marvin, of the chief signal office, exhibited a very delicate anemometer with conical cups made of aluminum, used to determine the constants of the anemometers of the service. The signal service exhibited a number of new apparatus, including the triple self-register for wind direction and velocity and rainfall. For obtaining the latter the gauge invented by Prof. Martin is employed. A float in a tube makes an electric contact by means similar to those in the anemometer, for each five-hundredths inch of rainfall. One of the new thermometers for registering electrically at a distance, made by Richard Brothers, of Paris, and just imported by the signal service for use at certain of its stations, was shown. The signal service also showed the apparatus used by Sergeant Park Morrill in his study of atmospheric electricity. This included the gas flame and mechanical collectors invented by Sergeant Morrill, the Trowbridge, Mascart, and Mendenhall quadrant electrometers, and the Mascart photographic register. The physical department of the Institute of Technology also added to this collection the Clifton and Thomson portable electrometers and the Thomson electrostatic voltmeter.

To the physical department of the Institute belonged the thermometer comparators shown. One of these was for making comparisons of a mercurial with an air thermometer, the other for comparing the thermometers used by the society's observers with a standard instrument, all being immersed in water for the purpose.

Desmond Fitz Gerald, of the Boston Water Works, sent from Chestnut Hill reservoir his recording rain gauge and the recording portion of his evaporimeter. In the former instrument, which has been in operation for many years, the water passes from the collector into a large cylinder in which a float moves in vertical guides. The attached pencil records the rainfall continuously upon a paper-covered drum revolved by a clock once a day. The evaporation apparatus was used in perhaps the most elaborate series of experiments ever carried out on evaporation, whose results have been published by Mr. Fitz Gerald.

The Draper Manufacturing Co. sent from New York a beautifully finished recording barometer and some thermometers, and the Standard Thermometer Co., of Peabody, Massachusetts, exhibited a tele-thermometer, metallic thermometers, and thermostats.

The signal service, besides the instruments previously mentioned, contributed sixty climatic and weather charts, eighteen photographs of the recording instruments at the central office, and two volumes of tornado drawings and photographs collected by Lieutenant Finley. A very fine collection of photographs was loaned by Henry P. Curtis. The forty photographs of lightning flashes belonged chiefly to Messrs. Curtis and McAdie. There were the English views of J. Guardia, M. Auty, R. Harris and E. S. Shepherd, and the American ones of L. S. Clarke, H. G. Piffard, G. R. Allerton, A. H. Binden, H. Butler and G. E. Davis, the three last gentlemen having contributed their own work. Dr. M. G. Parker had a number of views by the above artists exhibiting a peculiar rotary motion in lightning and other electrical discharges. The various types of discharges mentioned in the report of the thunder storm committee of the London Meteorological Society were clearly illustrated. Mr. Curtis also showed eighty photographs of clouds and surf and seventy-six views of the devastation caused by tornadoes, besides two which were said to be *bona fide* tornado clouds. Thirty photographs of frost work were contributed by the United States Signal Service, Miss Ledyard, Messrs. Curtis, Pike, and Rotch. Plans and views of the European mountain meteorological stations were exhibited by the latter gentleman.

Among the curiosities of the exhibition was a bottle and a saucer fused together by lightning, and a piece of window glass which had been ground translucent by the sand-bearing winds of Cape Cod. Prof. Abbe sent his printed weather bulletins, first issued in September, 1869, at the Cincinnati observatory. Soon after commencing telegraphic reports were received from fifteen stations, and on October 6, predictions for Cincinnati and vicinity were begun. The first weather map, issued May 1, 1886, at the Boston signal office, was shown by A. L. Rotch. The charting of weather maps at the sub-stations of the signal service and their duplication by the cyclostyle process was originated by Sergeant Cole, at that time in charge of the Boston station. This practice has since been extended to all important stations of the service in the United States, as explained in the September *Journal*.

Owing to the generous response to the circular requesting the loan of articles, particularly by the United States Signal Service, the exhibition was a success and was so well attended by visitors that it was continued three days longer than was originally intended. Now that the feasibility of such an exhibition has been demonstrated, it is to be hoped that others will follow, as there can be no doubt of their effect in stimulating the study of meteorology.—*Amer. Meteoro. Journal.*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